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Hydraulic backhoe pioneering and subgrading in low volume forest road construction.

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HYDRAULIC BACKHOE PIONEERING AND SUBGRADING IN LOW VOLUME FOREST ROAD CONSTRUCTION

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Abstract

Information was collected on thirty low volume forest road construction projects in Idaho and Montana as part of a road cost study by the U. S. Forest Service Intermountain Experiment Station in cooperation with the Civil Engineering Department of the University of Idaho. The investigation focused on the use of hydraulic track mounted backhoes in pioneering and subgrading. The specific objectives of the project were to describe the different backhoe construction systems, record and analyze pioneering and subgrading production rates, and estimate clearing, grubbing, and subgrade excavation costs based on equipment and labor hours.

Construction system characteristics, site and design factors, and production information was collected both by observing actual construction and by examining Forest Service construction records. The research showed that backhoe construction systems could be classified into three basic types: full use systems, minimum use systems, and balanced use systems, depending on system organization and pioneering technique. Analysis of the production data produced a regression equation that estimates backhoe pioneering production for the balanced use system based on site and road design factors.

The production regression equation was applied to actual project conditions to yield an estimate of backhoe pioneering time. Costs were then calculated based on appropriate labor and equipment rental rates and compared to actual project

costs. The cost estimation method presented may provide an alternative for estimating forest road pioneering and subgrade excavation costs.

A method of estimating backhoe pioneering excavation based on machine size, side slope and road design parameters is presented in the appendix. Also included is a computer program that incorporates the results of the study to provide estimates of pioneering excavation and production.

Acknowledgements

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Chapter 1. Introduction

Over the last five to ten years the hydraulic crawler mounted backhoe has replaced the crawler tractor dozer as the primary pioneering machine in the construction of low volume forest access roads in Idaho and Montana. Most forest road building contractors now operate with backhoes; those who do not most likely will switch over in the near future. The change to backhoes was brought about by improvements in backhoe performance and by the institution of stricter road building requirements in the interest of protecting and improving water quality.

Not much information on backhoe construction methods and production exists. The Forest Engineering Research Institute of Canada (FERIC) produced two reports in 1978 and 1982 on hydraulic backhoe road construction(1,2). The first, by M. M. Nagy, was a detailed productivity and cost comparison between four subgrade construction machines, a hydraulic backhoe, a crawler tractor dozer, a line shovel, and a hydraulic shovel loader. His report contains a good break down of backhoe function and production rates for individual road building tasks, and he indicates the backhoe has the lowest per unit subgrading cost, but the scope of the test was limited to a single machine in each class on a single site over a relatively short section of road. The second report by E. I. Stjernberg covers the use of hydraulic backhoes in central and eastern Canada.

A few other articles are available, notably one by B. W. Lea describing a backhoe construction system used on the Bitterroot National Forest (Montana) (3), and a series of Sales Engineering Bulletins on the use of hydraulic excavators for forest road building published by the Caterpillar Tractor Company (4).

In light of the increasing popularity of hydraulic backhoe road construction and noting the lack of available production information, Region One of the U.S. Forest Service sponsored a study of the use of hydraulic backhoes in forest road construction in cooperation with the Forest Service Intermountain Experiment Station and the Civil Engineering Department at the University of Idaho. The study had three main objectives: the first was to describe the operating methods of contractors using backhoes, the second was to collect production information and derive a regression equation relating production to measurable site and construction system factors, and the third was to use production estimates to estimate road building costs. This report summarizes the methods and findings of that study.

Advantages Of Backhoes in Forest Road Construction

Most backhoe systems combine several road building tasks into one operation, reducing non-productive machine time. An experienced operator will bunch logs, build slash windrows, and excavate most of the subgrade on the pioneering pass. The pioneering backhoe can also install culverts at live water

crossings and treat drainage problems as they are encountered. following pioneering, the backhoe can excavate cross drains and forward slash for disposal. With proper attachments, the backhoe can fell timber and load logs. This efficiency and versatility has contributed to the backhoe's success with road contractors. During the study, operators, contractors and engineers were asked to define what they felt were the advantages of backhoes in forest road construction. The advantages most often cited were:

1. Backhoes tend to incorporate less slash into embankments and have more control over fill placement.

2. Backhoes break fewer logs during clearing.

3. Slash piles and windrows built by backhoes contain less soil.

4. Backhoes can often work in wetter soils without adverse impact; which may extend the construction season.

5. Backhoes can excavate and tend burn pits, which allows more slash to be disposed in a single location.

6. Backhoes can excavate sliver cuts and can perform ditch and culvert basin maintenance in reconstruction.

Chapter 2. General Method of Backhoe Road Construction

Contractors have developed construction systems to take advantage of the backhoe's ability to efficiently sort and move materials within a set working radius. The construction system consists of the road building equipment, the crew and the organization required to complete a road building task; in particular, the clearing , slash disposal and excavation required to build a forest road to final subgrade. Most backhoe construction systems accomplish this work in three passes: the first pass clears the right of way and builds the pioneer road, the second decks logs and transports slash for disposal, and the third completes the subgrade excavation. Hydraulic backhoes can work in any of the phases, but are used mainly for pioneering and slash disposal.

The pioneering backhoe performs five activities: log bunching, slash consolidation, grubbing, excavation, and travel. These activities combine in a 10 to 20 minute cycle in which a short section of pioneer road is constructed. Figure 2-1 shows the approximate percentage of time spent on each activity.

Although the pioneering method may vary somewhat between operators, the following sequence of events describes a fairly typical pioneering cycle. The operator starts by moving the backhoe to the end of the existing pioneer road. Timber cutters work a safe distance ahead and fall timber parallel to

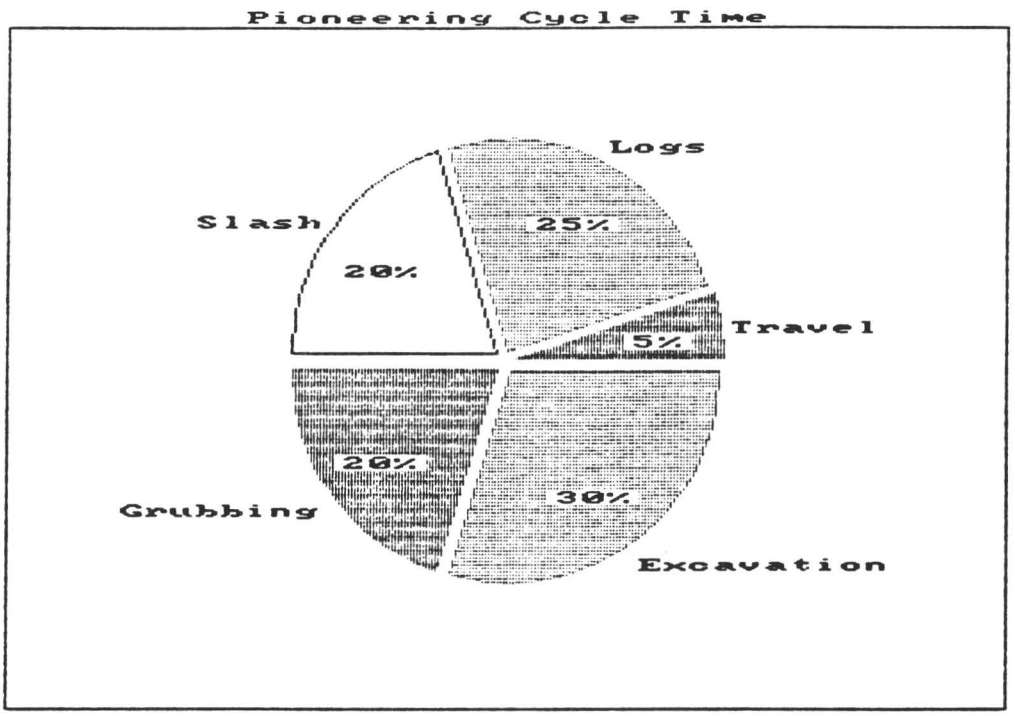

Figure 2-1. Pioneering Cycle Time

the right of way and buck to the desired log length. The operator positions the machine so that it is nearly level and has enough room to swing past the cut bank. Working from a stationary position, the operator begins clearing ahead of the backhoe, swinging logs behind and placing them along the lower edge of the pioneer road. Logs are angled toward the road to facilitate later skidding operations.

The pioneering backhoe has a reach of about 35 feet and is fitted with a hydraulic thumb attached to the under side of stick just above the bucket. This clamping mechanism greatly enhances the backhoe's log and slash handling abilities, enabling an operator to pick up large logs off center or to

collect and swing several small logs at a time. The thumb can be folded up against the stick during excavation.

After clearing the logs, the operator rakes in slash and windrows it against the lower clearing wall, taking care to place the slash far enough behind so that it is not covered during excavation. An experienced operator will build a clean and compact windrow, which will help reduce the time spent on clean up and recompaction. Tight dirt free windrows can also act as sediment barriers and may reduce the amount of sediment transported from the road way during and after construction.(5) Under specifications where windrowing is the final slash treatment, operators take special care to place logs so they can be skidded with a minimum of disturbance to the windrow.

Next, the operator grubs stumps and extends the pioneer road. Backhoes can apply a considerable amount of break out force to the bole of a stump, often enabling an operator to tip out a stump with a single pull. Stumps offering more resistance may have to be excavated on two or more sides, or they may be split with the bucket teeth and extracted a section at a time. Splitting will release some soil locked between the roots, which can be an advantage when fine fill material is scarce. Some operators will mash the roots with the thumb and drop the stump on the roadway to dislodge soil. Stumps may be deposited with the slash, scattered behind the windrow, or set above the cut bank depending on the disposal specification.

After the stumps are out, the operator finishes excavating the pioneer road, bringing down the cut at the required back slope on self balanced sections and leveling the road with the back of the bucket. After excavation, the operator moves ahead on the completed section, repositions the backhoe for clearing and begins another pioneering cycle.

As the pioneer road is extended, the pioneering backhoe may uncover hidden seeps, encounter wet areas or cross live streams. These situations, which may present water quality problems and slow or stop construction, can be treated promptly with the backhoe. Backhoes can quickly construct dewatering trenches which will divert water from the road way and drain wet subgrades. Some contractors require the pioneering backhoe to lay culverts at live water crossings, but most install temporary culverts and leave the permanent installation for a special pipe crew. Temporary culverts have been constructed with small diameter flexible drainage pipe, small diameter corrugated metal pipe and logs.

Logs set up by the backhoe on the first construction pass are hauled to decking areas by a skidding machine. Tracked backhoes have low travel speeds, most have maximums under 3 miles per hour, and have limited haul capabilities , so a separate machine specifically designed for transporting logs and slash is desirable. The skidding machine is usually a wheel skidder or medium sized crawler tractor and may follow immediately behind the pioneering backhoe or work just ahead of the slash disposal crew on the second construction pass.

The amount of work performed on the second pass depends on the slash disposal method. Under pile and burn specifications, slash windrowed during pioneering must be pulled back up to the road and transported to a disposal area. Permanent windrows will normally require some cleanup and consolidation after log skidding. The pioneering backhoe may perform these duties, or another, often times smaller, backhoe is used.

Slash set up by the slash disposal backhoe is transported to burn bays or burn pits by wheel or track mounted loaders. The burn bays and pits are cleared and excavated by the disposal backhoe as slash disposal progresses. Distances between disposal areas vary from 1000 to 1500 feet, which, under most conditions, gives the backhoe enough time to clear and excavate the disposal areas, and also perform its slash disposal function. The slash disposal crew may be required to install the permanent culverts.

After the logs have been decked and the slash has been cleared from the right of way, a large dozer, usually equipped with rippers, finishes excavating the subgrade on the third construction pass. The amount of dozer excavation depends upon road design and pioneering technique, but generally it will work mostly on sections with high cuts and fills requiring substantial end haul. In addition, the dozer may have to finish sections with tough rippable or blasted rock. Leaving the heavy earthwork to the dozer ensures that

it will be working nearer its capacity, which increases the overall profitability of the project.

Upon completion of the third construction pass, many lower standard haul roads may be servicable or can be brought into service with minor cleanup and finish grading. On projects requiring surfacing, or special drainage structures, the work proceeds in the conventional manner, with the backhoe assisting in excavation and material handling.

Chapter 3. Factors Affecting Pioneering Production

The description of the three-pass construction sequence in chapter 2. identifies equipment functions and describes the general operating methods of a common backhoe road construction system. Ideally, work is assigned to various machines and organized to maximize economic production. To help meet this goal, a construction system should account for the effects of road design and site characteristics on machine production. The pioneering backhoe, because of its clearing, grubbing and access excavation function can be greatly affected by these factors and can set the pace for machines in the system. An examination of the factors affecting backhoe production can be helpful in determining optimum equipment organization.

Pioneering backhoe production is influenced by elements from three main areas: road specifications and design, site and terrain factors, and construction system organization. Road standards were consistent among the projects. Most called for a fourteen foot roadway with turnouts and curve widening. On the average, rights of way were 48 ft. wide with approximately 2.2 cu. yd. of excavation per linear foot of subgrade, and the average favorable grade was 5.2% while the average adverse grade was 4.0%. Slash disposal methods varied from permanent windrowing to pile and burn and scattering.

Clearing width and grade have a substantial effect on pioneering production. On flat ground pioneering backhoes

have a practical working radius of around 35 feet, or if on a centered pioneer road an operator can clear a 60 foot right of way without moving the backhoe laterally. Horizontal working radius decreases on sloped ground and the maximum clearing width is reduced if the pioneer road is off to one side of the right of way. (In a full bench section on a 70 % side slope with a 1 : 1 cut slope, the maximum clearing width drops to about 40 feet.) Therefore, on sections with turnouts and curve widening, especially on steep ground, the backhoe may require two passes to reach all the clearing. Conversely, on flat ground clearing width may narrow to a point where the operator has trouble swinging the boom past trees on the edge of the right of way. A fact evidenced by cat faces high on the boles of clearing wall trees on some projects with constricted rights of ways. Operators suggest that a right of way be at least 30 feet wide. Clearing width is also an indicator of the amount of work the backhoe must perform durning log handling and slash consolidation.

The length and steepness of grade also affects production. Adverse grades in particular seem to slow down pioneering. For the purposes of this study, adverse grade is defined as going downhill (negative grade) in the direction of increased stationing, which matches the conventional definition of adverse; an uphill haul for a loaded log truck. An adverse grade for the backhoe requires that it pull logs, slash and stumps uphill, increasing the force necessary to move them and decreasing the backhoes sliding resistance under hard pulls.

Over-the-front stability is also reduced and the effective boom and stick weight is increased. A forward tilting cab may also cause some difficulty for the operator.

Site factors such as clearing volume, soil and timber type, and topography will also affect the rate, and in some cases the method of pioneering. Backhoes pioneer under a variety of conditions , from dense cedar-fir stands to the open and patchy timber found on drier ponderosa pine sites. Production increases as the volume of clearing decreases, but there is a point when clearing is so light that backhoes become uneconomic. Some contractors backhoe pioneer through heavy timber, then dozer pioneer through burn areas, clear cuts and open timber stands. In medium and heavy clearing, backhoe production also seems to be sensitive to the number of pieces handled. Piece count can be controlled somewhat during the felling operation. Contractors favor felling parallel to the right of way with logs bucked to the desired length for most situations. However, in dense pole sized timber a few contractors switched to tree length clearing to reduce the number of small diameter pieces that must be handled. Some contractors also require sawyers to buck sound windfalls in stands with large volumes of windthrow to help reduce breakage and handling.

Clearing time is also affected by the size and species of stumps. Operators say they can usually grub stumps of any species, up to two feet in diameter, fairly easily. Larger stumps can be more difficult to remove, especially deep tap

rooted species like ponderosa pine. Operators may increase production by leaving some stumps for the dozer to push out during final subgrading.

Side slope affects the volume of pioneering excavation. A backhoe essentially builds a level self balanced section as it extends the pioneer road; the steeper the ground, the more excavation required. On some designed self balanced sections the backhoe may excavate nearly all the subgrade, especially if the operator excavates down from the cut stake at the designed back slope. Excavation production will vary with material type. Pioneering through rock is slow, so most contractors excavate just enough to advance the backhoe to better ground. However, backhoes can excavate certain kinds of fractured or rippable rock (one contractor has mounted a ripper tooth on his bucket to help break loose rock). They also can move rocks in limited space, pulling rather than pushing rock out of a cut; an advantage when pioneering through outcrops or excavating blasting access.

In general, backhoe pioneering seems to be most economic on self balanced side hill sections through medium dense timber on slopes of 30 to 50 percent. Under these conditions, the backhoe has enough room to swing, yet can reach all the material in the right of way, and there is a good balance between clearing and excavation.

Chapter 4. Backhoe Pioneering and Subgrading Systems

Pioneering rate depends as much on the organization of the construction system as it does on site conditions and road specifications. The attempt to compare production between contractors is complicated by an inability to separate pioneering from major subgrade excavation and slash disposal. Pioneering method directly affects the amount of work performed during the slash disposal and subgrading phases. A comparison based primarily on the production of one phase, should also account for the contribution of the other machines in the system. This difficulty could be avoided by considering only the overall production of the system; defining productivity in terms of length of completed subgrade per unit time, but this would obscure the contribution made by the different components of the system. The approach taken in this study was to examine factors such as machine selection, equipment function, and pioneering technique, then combine these elements into a description of a construction system and restrict comparisons to equivalent systems.

Table 4-1 summarizes the equipment used on the projects examined by this study. The choice of pioneering backhoe is fairly consistent; most machines are between 135 and 185 hp. with a ground level reach of 30 to 37 ft. and a front lift capacity at mid reach of 11,000 to 24,000 lbs. All were equipped with hydraulic thumbs and most had reinforced booms and sticks. On the average, slash disposal backhoes were ROAD

smaller than the pioneering backhoe. When forwarding slash, the faster swing speed of a smaller machine is more advantageous than the greater excavating power of a larger machine. Some contractors used cranes instead of backhoes when scattering slash.

There was a slight preference for crawler tractors over wheel skidders when skidding logs behind the backhoe. They varied in size from a 65 Hp Caterpillar D3 to a 200 Hp Caterpillar D7. Some of the larger skidding dozers also performed subgrade excavation. Wheel skidders were used mainly in operations where the subgrading dozer worked fairly close the pioneering backhoe. Almost all slash transporting machines were track type and wheel type loaders. Some were equipped with grapples and doubled as skidding machines. Large dozers, 200 horsepower and above, were preferred for finishing the subgrade. Most had rippers and a few had slope boards.

Table 4-1 Summary of Road Construction Equipment

Hydraulic Backhoes	Pioneering Skidding Assist	Slash Forwarding	Slash Transport	Subgrading
	Wheel Skidders	Hydraulic Backhoes	Track Loaders	Dozers
9 Caterpillar 235	2 Caterpillar 518	5 Caterpillar 225	1 Caterpillar 977L	9 Caterpillar D8
7 Caterpillar 225	1 Caterpillar 528	4 Caterpillar 235	1 Caterpillar 955	6 Caterpillar D7
3 Hitachi Uh122	1 John Deere 740	3 Caterpillar 215		1 Komatsu D65E
1 Leibherr 942	1 John Deere 540A	2 Hitachi UH122	Wheel Loaders	1 Euclid C6
1 Leibherr 925	1 Clark 644	1 Hein Warner C14B	2 Caterpillar 966	1 John Deere 550
1 Drott 50D		1 Poclain 150SL	2 Caterpillar 950	
1 John Deere 690B	Crawler Tractors	1 John Deere 690B	1 Caterpillar 930	
1 Kohring Bantam 366	3 Caterpillar D6	Cranes		
	2 Caterpillar D7	3 Linkbelt 988	Skidders	
	2 Komatsu D65E		1 Caterpillar 528	
	1 Terex 8230			
	1 Caterpillar D3			
	1 Caterpillar 977L			

The amount of work assigned to the backhoe varies between contractors and is influenced by road building conditions, available equipment, and experience. This in turn affects the overall pioneering method, producing variations from the general method discussed earlier. Slash is usually windrowed during pioneering, but contractors may use other methods under special circumstances. For example, in the winter one contractor has his backhoe pile slash in the road for immediate transport to disposal areas in order to keep logs and slash from being covered by snow. Another builds small slash piles, a boom's reach apart, at the toe of the pioneer road to be burned later without further machine handling.

Similarly, log and stump handling techniques will vary. Logs may be mixed randomly in the windrow or bunched on top for better skidding access. The backhoe may also forward logs directly to a skidding machine if the two machines work fairly close together. Likewise, stumps can be mixed in the slash or placed on top of the windrow, or placed above the cut slope. Exposing stumps on the windrow or cut bank speeds drying, making them easier to burn under pile and burn specifications. On projects that allow scattering, stumps were sometimes thrown behind the windrow on the pioneering pass, reducing the volume of material that had to be handled in the disposal operation.

The volume of pioneering excavation varies greatly from one system to another; some pioneering backhoes excavate just enough for a level set with room to swing while others

excavate much more. The amount of excavation beyond that necessary for stability and free movement depends in part on material type and clearing width, but mostly it is a function of the contractors objectives for the pioneering backhoe. Some contractors excavate only the minimum in fill areas (figure 4.2A), then excavate all the subgrade on self balanced sections (Figure 4.2B). Others excavate the minimum volume nearly all the time, while still others will attempt to perform all the excavation with the backhoe. This variability makes pioneering excavation a key consideration when comparing the performance of one pioneering backhoe against another, and helps provide the basis for a method of classifying backhoe pioneering and subgrading systems.

Backhoe pioneering and subgrading systems can be broadly classified into three categories: full use, minimum use, and balanced use; depending on the amount of work performed on the pioneering pass. In minimum use systems, the pioneering backhoe performs just enough work to consolidate slash and logs and provide access for slash disposal and subgrading equipment. Logs, stumps, and slash are randomly mixed in a temporary windrow with no extra effort spent on separating logs from slash. Excavation is minimal, with no cut slope work and stumps outside the pioneer road are sometimes left for the subgrading dozer. Pioneering is accomplished in a single pass and the pioneer road may be moderately outsloped.

In full use systems the pioneering backhoe performs as much slash disposal and subgrade excavation as possible within

the limits posed by road design and machine capabilities. The operator clears and grubs the right of way, decks logs, and places slash and stumps in their permanent disposal locations. He also excavates all of the subgrade, even sections with end haul if excavation can be loaded directly into haul machines. He may have to make two or more passes to finish the construction and probably will install culverts. Full use systems are normally applied to self balanced roads through moderate terrain with medium clearing.

In balanced use systems, the backhoe is assigned tasks that compliment the use of other slash handling and excavation equipment. Work is divided among the machines in the system so that overall construction cost is minimized. In this type of system the pioneering backhoe usually clears and grubs the right of way and places logs and slash so they can be handled more efficiently in the skidding and slash disposal operations. Also, the backhoe excavates beyond what is necessary for access, often bringing down back slopes and rounding the top of the slope, but leaving the heavy earthwork for a subgrading dozer. Most backhoe construction systems are in the balanced use category , including the system described in chapter 2.

Following are descriptions of actual backhoe construction systems in each category:

Case 1: Minimum Use System

Equipment: Caterpillar 235 with brush grapple
Caterpillar D7 with rippers
Linkbelt 998 crane

Site:

Mixed fir and cedar, medium density (140 trees per acre) with an average diameter of 14 inches.

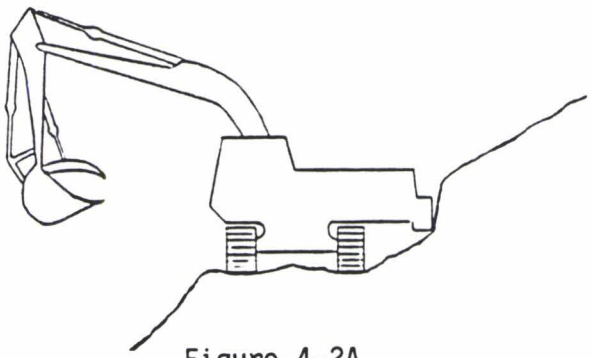

Figure 4-2A

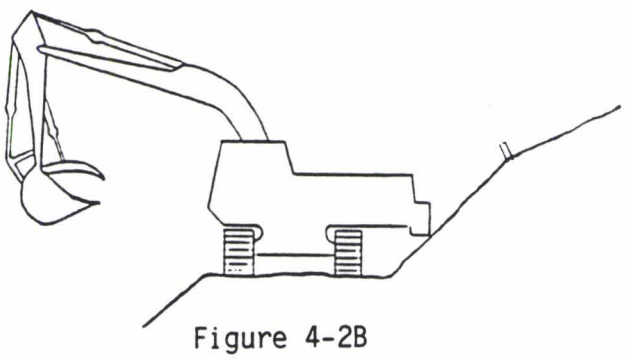

Figure 4-2B

Figure 4-2 Backhoe Pioneering Cross Sections

Side Slopes varied from 30 to 50 percent with an average of 40 percent. The excavation was common with less than 10 percent rippable rock. The road was constructed in July, with excellent weather and good working conditions.

Road Design:

A Standard U.S. Forest Service 14 ft. road with turnouts and curve widening. The road was staked prior to construction and had a short section of reconstruction (not included in the production data). The average clearing width was 45 feet and the average grade was 5 percent favorable. There was about 1.0 cu. yds. of excavation per linear foot of subgrade and fill was to be placed by either side casting or end dumping. Slash could be scattered.

Operating Method:

The backhoe cleared and grubbed the right of way, and placed logs, slash, and stumps in a windrow at the toe of the pioneer road on the first pass. Logs were not separated from the slash and the backhoe did not scatter slash while pioneering. Some stumps were broken apart and a few larger stumps were left for the dozer. Pioneering excavation was generally minimal, but the operator often brought down the cut slope to the pioneer grade and would have installed culverts when

encountered (there were none on the study section). The average pioneering rate was 180 feet per hour; the highest among the projects studied. After 7.5 hrs of pioneering the backhoe operator switched to the D7 dozer for the rest of the 10 hr day, and smoothed the pioneer road and pushed out the remaining stumps.

On the second pass, the 998 crane scattered the windrowed slash and stumps outside the clearing limits. Logs were placed in decks 30 to 50 feet apart and were to be loaded on trucks as the crane worked its way back down the road. The slash disposal rate was estimated to be about 1000 feet per day (100 ft / hr). After the logs were hauled the D7 dozer completed the subgrade excavation. There was no estimate of dozer production.

Case 2: Full Use System

Equipment:

Caterpillar 235 with hydraulic thumb, heavy duty boom and extra fuel capacity.

Site:

Western larch and lodgepole pine, medium density (150 trees / acre) with an average diameter of 12 inches. Slopes vary from 40 to 60 percent with an average

about 50 percent. Excavation was mostly common with less than 10 percent rippable. Construction occurred during August under good operating conditions.

Road Design:

A Standard U.S. Forest Service 14 ft. road with turnouts and curve widening. The road was staked prior to construction and was self balanced. The average clearing width was 50 feet and the average grade was 5 percent favorable. There was about 2.3 cu. yds. of excavation per linear foot of subgrade and fill was to be placed by either side casting or end dumping. The slash disposal specification called for pile and burn disposal.

Operating Method:

The backhoe cleared and grubbed the right of way and placed slash and stumps in small piles against the clearing wall as far apart as could be reach from a single set, about 70 feet. This method of slash disposal reduced travel and was well adapted to the capabilities of the backhoe. The numerous small piles were to be burned in place and probably increased tending and cleanup time. Logs were decked between the slash piles. The backhoe performed nearly all the excavation and pulled down the back slopes and kept the road on grade.

A dozer and grader were to level the road and pull the ditches at the end of the project. Backhoe production was about 45 feet per hour.

Case 3: Full Use System

Equipment:

Caterpillar 225 with brush grapple and two piece boom.

Site:

Mixed grand fir and Douglas fir with some ponderosa pine, light to medium density (100 trees / acre) with an average diameter of 18 inches. Slopes varied from 20 to 30 percent and excavation was common with less than 10 percent rippable. The road was constructed in August under good operating conditions.

Road Design:

A Standard U.S. Forest Service 14 ft. road with turnouts and curve widening. The road was staked prior to construction and was self balanced. The average clearing width was 40 feet and the average grade was 5 percent favorable. There was about 0.8 cu. yds. of excavation per linear foot of subgrade and fill was to

be placed by either side casting or end dumping. The slash disposal specification called for pile and burn disposal.

Operating Method:

The backhoe cleared and grubbed the right of way, and placed logs behind and crosswise on the road where a sawyer removed remaining limbs and checked bucking lengths. Slash was placed in small temporary piles at the toe of the road while the backhoe was excavating. After approximately 500 feet of road was pioneered, the operator collected the small slash piles and transported them to natural breaks in the clearing wall. The larger piles were easier to burn and took advantage of natural burn bays, but increased backhoe travel time. Logs were transported to decks between the slash piles. The backhoe excavated most of the subgrade and installed temporary culverts at live water crossings.The average pioneering rate was 77 ft per hour.

The contractor was to bring a grader in at the end of the project to smooth the road and had a D7 dozer available to provide access to the backhoe in case of a break down.

Case 4: Balanced Use System

Equipment: Caterpillar 235 with hydraulic thumb
Caterpillar 215 with hydraulic thumb
John Deere 740 skidder with grapple
Caterpillar 966 wheel loader
Caterpillar D7 with rippers

Site:

Mixed lodgepole pine, hemlock, spruce, and subalpine fir, extra light to medium clearing(less than 150 trees per acre) with an average diameter of 12 inches. Slopes varied from 20 to 70 percent (with an average of 45 percent)and the excavation is common and rippable with some outcrops that required blasting. The road was constructed during August and September under good conditions.

Road Design:

A Standard U.S. Forest Service 14 ft. road with turnouts and curve widening. The road was staked prior to construction ~~and was~~ and had some sections with substantial haul. The average clearing width was 34 feet and the average favorable grade was 6.0 percent while the average adverse grade was 4.8 percent. There was about 1.4 cu. yds. of excavation per linear foot of subgrade and fill was to be placed by either side casting or end dumping. Slash was placed in a permanent windrow.

Operating Method:

The Caterpillar 235 cleared and grubbed the right of way and placed the slash in a temporary windrow at the toe of the pioneer road. Stumps were broken and scattered behind the windrow and logs were placed at the edge of the road for skidding by the John Deere 740. Overall, the backhoe excavated 50 percent of the subgrade on the pioneering pass with near 100 percent excavation on self balanced sections. The operator lightly excavated rocky sections, moving only enough to allow passage. Pioneering rate averaged 85 feet per hour through medium clearing and 144.6 feet per hour through the light and extra light clearing.

On the second pass, the Caterpillar 215 pulled slash from the windrow and forwarded it to the wheel loader, which transported it to disposal areas. The slash disposal crew also installed culverts. The slash disposal rate (not including culvert installation) was 86 feet per hour.

After slash disposal, the Caterpillar D7 dozer finished excavating the subgrade, mainly working on sections with end haul or rock. Dozing rate was 128 feet per hour.

Chapter 5. Data Collection and Regression Analysis

Data Collection

Information was collected on 30 forest road construction projects, involving 19 contractors on 10 National Forests in Region 1 (Table 5-1). Twenty-three of the projects were observed during construction and all projects were visited at least once to collect information on site characteristics and road design. Production information was determined by measuring machine progress while monitoring construction and by reviewing forest service construction records. Data collection consisted of the following steps:

1. An initial contact with the Forest Zone Engineer to determine likely projects, current or past, that involve backhoe pioneering and subgrading.

2. A conference with a suggested project's chief engineer and inspectors to evaluate existing production information and to obtain views and observations on backhoe construction.

3. Acquisition of construction records (inspector's diary), road plans, timber cruise data, payroll records, and construction bid summary (if available).

Table 5-1 Hydraulic Backhoe Pioneering Projects

Project	Forest	Contractor	Construction System
Clear Creek	Nezperce	A	Balanced
Center Star	Nezperce	A	Balanced
Basin Porcupine	Kootenai	A	Balanced
Noseeum Creek	Kootenai	A	Balanced
Stateline	St. Joe	A	Balanced
Beaverhead Road	Beaverhead	B	Minimum
Bull Ridge	Clearwater	C	Full
Highline	St. Joe	D	Balanced
Neva Hill	St. Joe (Palouse)	D	Balanced
Carrico Mine	St. Joe (Palouse)	D	Balanced
Coal Ridge	Flathead	E	Balanced
Circus Peak	Flathead	E	Balanced
Purdee Creek	Lolo	F	Full
Dutch Anthony	St. Joe	G	Balanced
Rye Creek	St. Joe	G	Balanced
Elk Mountain	Coeur d'Alene	H	Minimum
Four Teir	Coeur d'Alene	H	Minimum
Headlong Creek	St. Joe (Palouse)	I	Balanced
Lower Huckleberry	Payette	J	Balanced
Knoll Creek	Clearwater	K	Balanced
Lower Deadman	Clearwater	K	Balanced
Little Thompson	Lolo	L	Balanced
Lookout Standard	Flathead	M	Balanced
North Creek	Kaniksu	N	Balanced
Rice Paddy	Kootenai	O	Balanced
Tyson Sheep	St. Joe	P	Minimum
Upper Huckleberry	Payette	Q	Minimum
Wolf Mountain	Kootenai	R	Balanced
Huckleberry Heaven	Nezperce	S	Minimum
Halls Gultch	Nezperce	S	Balanced

4. A visit to the site to observe construction methods, determine site characteristics and measure production data.

5. Evaluate subsequent production data collected by road inspectors on selected projects.

6. Define sections with homogeneous site characteristics, road specifications, and construction methods on roads with adequate production data.

7. Evaluate the road plans and specifications to determine road quantities and design parameters for the homogeneous sections.

Nineteen of the thirty projects had sufficient production data to provide the basis for a pioneering rate regression analysis. Only projects with at least a week of measured production or daily production records (from the Engineer's diary) were included in the analysis. Nine projects possessed enough site variability to allow several homogeneous sections, resulting in a total of forty seven test sections.

Site factors examined include average side slope, excavation type (soil type), Forest Service clearing classification, and timber type. Road quantities and parameters were also examined to determine their bearing on production, they include total excavation per linear foot of subgrade, average clearing width, favorable and adverse grade (percent), percent of road in favorable and adverse grade, the month of the year when construction occurred, and an estimate of pioneering production based on side slope and machine dimensions. Tables 5-2 and 5-3 summarize the site factors and

road parameters for each homogeneous section. The table column headings are defined in greater detail in the Appendix 1., along with the method of collection.

Backhoe Pioneering Regression Analysis

The second major objective of the study was to determine the degree of correlation between backhoe pioneering production rates and measurable site characteristic and road design factors. The factors tested in the regression included: design subgrade excavation, estimated pioneering excavation, section length, clearing width, steepness and relative length of adverse and favorable grades, clearing density, side slope, relative amount of rippable rock, month of construction, and machine horsepower. After examining the data, it was determined that there was insufficient information to perform a regression on the full use and minimum use constructions systems, so the analysis was limited to sections built by the balanced use construction system.

A stepwise regression analysis was performed on the sections listed in Tables 5-2 and 5-3 using the Statistical Analysis System (SAS) computer program available on the University of Idaho computer system. Variables were accepted for inclusion in the regression model if the significance probabilities of the F statistic computed with the partial sum of squares (sum of squares adjusted for all other independent variables) was less than 0.15.

Table 5-2 Backhoe Pioneering Test Sections: Site Factors

Section	Pioneering System	Pioneering Machine	Rate ft/hr	Length Stations	Side Slope %	Soil Class	Clearing Class	Timber Type
Basin Porcp. 2	Bal Use	Cat 235	94.3	141.50	40	Com	Heavy	lp
Basin Porcp. 3	Bal Use	Cat 235	160.8	128.64	32	Com	Med	lp
BeaverHead	Bal Use	Cat 225	100.0	10.00	50	RR10	Light	DF/LP
Clear Creek 1	Bal Use	Cat 235	44.0	13.20	39	Com	Heavy	GF
Clear Creek 2	Bal Use	Cat 235	93.3	28.00	39	Com	Heavy	GF
Clear Creek 3	Bal Use	Cat 235	82.5	33.00	38	Com	Heavy	GF
Clear Creek 4	Bal Use	Cat 235	55.4	14.95	52	Com	Heavy	GF
Clear Creek 5	Bal Use	Cat 235	70.7	25.46	53	Com	Heavy	GF/WRC
Coal Ridge 1	Bal Use	Cat 235	66.0	13.00	58	RR50	Med	DF/WL/LP
Coal Ridge 2	Bal Use	Cat 235	45.0	36.00	64	RR50	Med	DF/WL/LP
Coal Ridge 3	Bal Use	Cat 235	40.0	4.00	70	RR50	Med	DF/WL/LP
Coal Ridge 4	Bal Use	Cat 235	67.0	12.00	70	Com	Med	DF/WL/LP
Coal Ridge 5	Bal Use	Cat 235	56.0	5.00	70	RR50	Med	DF/WL/LP
Coal Ridge 6	Bal Use	Cat 235	71.0	12.00	50	Com	Med	DF/WL/LP
Coal Ridge 7	Bal Use	Cat 235	127.0	33.00	30	Com	Med	DF/WL/LP
Coal Ridge 8	Bal Use	Cat 235	86.0	31.00	35	Com	Med	DF/WL/LP
Dutch Anth. 1	Bal Use	Cat 225	68.5	73.00	34	Com	Med	GF/WRC
Dutch Anth. 2	Bal Use	Cat 225	70.4	19.00	36	Com	Med	GF/WRC
Dutch Anth. 3	Bal Use	Cat 225	63.3	19.00	43	Com	Med	GF/WRC
Dutch Anth. 4	Bal Use	Cat 225	36.8	14.00	50	Com	Med	GF/WRC
Dutch Anth. 5	Bal Use	Cat 225	87.8	26.33	33	Com	Med	GF/WRC
Dutch Anth. 6	Bal Use	Cat 225	76.0	19.00	40	Com	Med	GF/WRC
Dutch Anth. 7	Bal Use	Cat 225	70.0	14.00	45	Com	Med	GF/WRC
Dutch Anth. 8	Bal Use	Cat 225	99.6	5.81	53	Com	Light	GF/WRC
Headlong 1	Bal Use	Hit. UHI22	45.3	12.90	40	Com	Med	GF/WRC
Headlong 2	Bal Use	Hit. UHI22	46.8	20.53	40	Com	Med	GF/WRC
Headlong 3	Bal Use	Hit. UHI22	59.6	75.98	40	Com	Med	GF/WRC
Knoll Creek	Bal Use	Cat 225	80.3	11.65	50	Com	Med	DF/GF
Lower Deadman	Bal Use	Cat 225	62.5	91.00	50	Com	Med	GF/WRC
Ltl. Thompson	Bal Use	Cat 225	75.0	30.00	41	RR40	Med	LPP/SAF
Neva Hill 1	Bal Use	Liebh. 942	73.4	40.05	45	Com	Med	GF/WRC
Neva Hill 2	Bal Use	Liebh. 942	78.9	30.00	45	Com	Med	GF/WRC
Noseeum 1	Bal Use	Cat 235	82.3	41.15	53	Com	Med	GF/WRC
Noseeum 2	Bal Use	Cat 235	103.4	41.36	43	Com	Med	GF/WRC
Rice Paddy 1	Bal Use	Cat 235	111.1	10.00	15	Com	Light	DF/LP
Rice Paddy 2	Bal Use	Cat 235	62.9	56.00	40	RR10	Light	DF/LP
Rice Paddy 3	Bal Use	Cat 235	97.3	18.60	60	RR10	Ex Lt	Brush
Stateline 1	Bal Use	Cat 235	85.0	34.00	31	Com	Med	ES/SF/LP
Stateline 2	Bal Use	Cat 235	85.0	43.00	41	Com	Med	ES/SF/LP
Stateline 3	Bal Use	Cat 235	111.7	33.50	47	Com	Light	ES/SF/LP
Stateline 4	Bal Use	Cat 235	153.6	127.90	47	Com	Light	ES/SF/LP
Basin Porcp. 1	Full Use	Cat 225	80.4	131.05	38	Com	Heavy	LP
Bull Ridge	Full Use	Drott D50	40.0	10.00	55	RR100	Med	GF/WRC
Huckleberry	Full Use	Cat 225	85.2	10.00	20	Com	Med	GF
Purdee	Full Use	Cat 235	45.0	10.00	55	Com	Heavy	LP
Four Teir	Min Use	Cat 235	180.3	40.00	40	Com	Med	GF/WRC
Tyson Sheep	Min Use	Liebh. 925	76.0	38.10	32	Com	Med	GF/WRC

Table 5-3 Backhoe Pioneering Test Sections: Road Parameters

Section	Excv cy/ft	Pion Excv cy/ft	Clearing Width (ft)	Grade % Avg Fav	Length % Fav	Grade % Avg Adv	Length % Adv	Month
Basin Porcp. 2	1.0	0.55	30	2.1	35	3.3	65	10
Basin Porcp. 3	0.8	0.35	29	5.2	45	4.2	55	10
BeaverHead	2.6	0.89	47	5.0	100	0.0	0	8
Clear Creek 1	5.0	0.52	59	7.7	39	4.0	61	8
Clear Creek 2	2.3	0.52	46	5.6	34	4.4	66	8
Clear Creek 3	4.5	0.49	56	5.2	24	4.7	76	9
Clear Creek 4	7.8	0.96	60	5.1	100	0.0	0	10
Clear Creek 5	5.6	1.02	58	3.2	30	7.0	70	10
Coal Ridge 1	4.1	1.32	62	9.4	100	0.0	0	8
Coal Ridge 2	4.1	1.94	57	6.9	44	3.7	56	8
Coal Ridge 3	4.0	2.20	54	4.9	100	0.0	0	7
Coal Ridge 4	3.2	2.20	54	11.0	100	0.0	0	8
Coal Ridge 5	4.8	2.20	54	11.0	100	0.0	0	9
Coal Ridge 6	3.8	0.89	56	7.4	75	2.6	25	8
Coal Ridge 7	2.6	0.31	42	9.0	96	2.9	4	8
Coal Ridge 8	1.7	0.42	40	4.6	29	5.4	71	8
Dutch Anth. 1	1.9	0.40	55	5.4	93	0.6	7	6
Dutch Anth. 2	2.9	0.44	60	4.3	68	4.3	32	6
Dutch Anth. 3	2.0	0.63	50	3.6	3	5.4	97	7
Dutch Anth. 4	5.0	0.89	66	7.2	61	6.3	39	8
Dutch Anth. 5	2.0	0.37	49	0.0	0	7.8	100	9
Dutch Anth. 6	1.2	0.55	41	5.6	84	2.3	16	9
Dutch Anth. 7	1.7	0.70	51	5.1	46	7.4	54	8
Dutch Anth. 8	3.4	1.02	54	5.1	34	7.9	66	8
Headlong 1	2.5	0.55	52	0.0	0	8.8	100	7
Headlong 2	1.7	0.55	49	2.8	12	10.7	88	8
Headlong 3	2.4	0.55	47	3.5	28	7.2	72	8
Knoll Creek	2.0	0.89	58	1.0	28	5.3	72	7
Lower Deadman	2.0	0.89	48	4.3	26	7.6	74	7
Ltl. Thompson	1.9	0.58	45	7.6	100	0.0	0	8
Neva Hill 1	2.3	0.70	43	6.9	64	8.2	36	9
Neva Hill 2	2.2	0.70	45	4.6	32	4.8	68	10
Noseeum 1	2.8	1.02	51	8.1	100	0.0	0	6
Noseeum 2	1.4	0.63	42	6.1	41	12.0	59	12
Rice Paddy 1	0.3	0.06	30	4.9	85	0.2	15	2
Rice Paddy 2	1.5	0.55	30	7.0	100	0.0	0	3
Rice Paddy 3	2.4	1.48	40	4.4	100	0.0	0	4
Stateline 1	0.9	0.33	31	7.5	100	0.0	0	8
Stateline 2	1.2	0.58	32	4.0	7	6.3	93	8
Stateline 3	1.5	0.77	34	3.2	33	4.3	67	9
Stateline 4	1.6	0.77	36	5.9	82	3.1	18	10
Basin Porcp. 1	0.7	0.49	26	5.5	47	4.5	53	9
Bull Ridge	4.0	1.13	45	5.0	100	0.0	0	8
Huckleberry	0.3	0.13	40	5.0	100	0.0	0	8
Purdee	2.3	1.13	60	5.0	100	0.0	0	7
Four Teir	1.0	0.55	50	5.0	100	0.0	0	7
Tyson Sheep	2.6	0.35	53	5.2	57	6.2	43	7

The stepwise procedure indicated that clearing width, clearing class, pioneering excavation volume, month, and weighted adverse grade, were significant and resulted in a coefficient of determination (R-squared) of 0.647. Table 5-4 contains the model coefficients, standard error of the estimates and the T statistic significance probability, where the T statistic tests the hypothesis that the variable coefficient is zero (should not be included in the model). A low T probability indicates that the variable is significant.

Table 5-4 Stepwise Regression Analysis: Balanced Use Projects

Variable entered*: EXCV, PXCV, LENGTH, CLEARING WIDTH, FAV, ADV, CLEARING CLASS, SIDE SLOPE, SOIL TYPE, MONTH, HORSEPOWER

Variable	Coefficient	Standard Error	Significance Probability > T
INTERCEPT	145.225	17.370	0.0001
PXCV	- 16.271	6.167	0.0123
CLEARING WIDTH	- 1.096	0.338	0.0026
CLEARING CLASS	- 16.026	4.646	0.0015
ADV	- 0.030	0.012	0.0145
MONTH	6.734	1.736	0.0004

Coefficient of Determination (R squared) = 0.647

* Definition of variables in Appendix 1

The variables selected by the stepwise regression analysis seem appropriate and affect production in a reasonable manner. Clearing width and clearing class are a measure of the amount of work the backhoe must perform in clearing the right of way; the wider the clearing width the more gross area that has to be cleared. Clearing class is a numerical classification of

clearing density, based on tree diameter and spacing, used by the U.S. Forest Service (1-extra light to 5-extra heavy). ADV, is the percent of total section length in adverse grade multiplied by the slope of the adverse grade in percent. An adverse grade requires that the backhoe work facing downhill, increasing the amount of energy expended during clearing and excavation. PXCV is an estimate of the amount of pioneering excavation based on side slope and machine specifications and can be calculated by the procedure presented in Appendix 2. Finally, MONTH represents the time of year the pioneering occurs. During the early part of the year soils may be poorly drained, tending to slow construction and weather may cause construction delays not completely documented in the construction record. Also, production may increase with time as the construction crew gains more experience and establishes an efficient work routine. There also may be a tendency for production to increase as a project nears completion towards the end of the construction season.

The coefficient of determination indicates that about 35 percent of the total variability is unaccounted for in the regression. It seems reasonable that a large portion of this variability is due to differences between contractors and operators. Also, some refinement can be expected if more precise measures of clearing density are substitued for the clearing classification.

To test this hypothesis, a second regression analysis was conducted using data from one contractor supplemented with additional timber characteristics. Table 5-5 summarizes the homogeneous sections for contractor A and the additional timber parameters used in this regression analysis.

The stepwise regression procedure indicated a strong correlation (R squared = 0.995) between pioneering rate and the independent variables SIDE SLOPE, CLEARING WIDTH, TREES PER ACRE, and DIAMETER * LOGS (Table 5-6). Again the variables selected are good indicators of the amount of work the backhoe must perform during pioneering. SIDE SLOPE acts as an indicator of the amount of pioneering excavation when machine size and pioneering method are held constant. CLEARING WIDTH, as before, determines the clearing area, but this time clearing density is is measured by the variables TREES PER ACRE and AVG DIAMETER * LOGS/ACRE. The additive effect of the TREES PER ACRE term is due to the dependence of LOGS/ACRE on the number of trees per acre, where:

$$\text{LOGS/ACRE} = \text{TPA} * \text{AVG HEIGHT} / \text{LOG LENGTH}$$

The magnitude of the negative AVG DIAMETER * LOGS/ACRE term will always be greater than the TPA term for all practical tree heights and diameters.

The results of this regression substantiates the hypothesis that a large portion of the unaccounted for

variability in the original analysis is due to contractor effects and the over generalized clearing density description.

A third regression analysis was performed on the data from all the balanced use sections using the general linear model procedure available on the SAS system. However, this time PXCV was replaced with SIDE SLOPE to note the effect of using this simpler indicator of pioneering excavation. The results are presented in Table 5-7. SIDE SLOPE has the same general effect as PXCV; a reduced pioneering rate as side slope (excavation) is increased, the predicted pioneering rate will vary up to about 10 feet per hour from the original equation, depending on the other variable settings. Recognizing that the coefficient of determination only dropped by 1.2 percent to 0.635 when SIDE SLOPE was substituted for PXCV, this equation should be as good as the original when predicting average pioneering rates.

Table 5-5 Backhoe Pioneering Test Sections: Contractor A

Section	Pion. Rate ft/hr	Side Slope %	Timber Type	Avg Diam in	Avg Ht ft	Trees per Acre
Basin Porcp. 2	94.3	40	LP	12	100	300
Basin Porcp. 3	160.8	32	LP	12	100	100
Clear Creek 1	44.0	39	GF	15	100	200
Clear Creek 2	93.3	39	GF	24	100	74
Clear Creek 3	82.5	38	GF	13	58	379
Clear Creek 4	55.4	52	GF	14	54	369
Clear Creek 5	70.7	53	GF/WRC	13	54	338
Noseeum 1	82.3	53	GF/WRC	13	79	192
Noseeum 2	103.4	43	GF/WRC	13	79	192

Table 5-6 Stepwise Regression Analysis: Contractor A

Variable entered*: EXCV, PXCV, LENGTH, CLEARING WIDTH, FAV, ADV, CLEARING CLASS, SIDE SLOPE, SOIL TYPE, MONTH, HORSEPOWER, AVG DIAMETER, TPA, AVG HEIGHT, D*TPA, LOGS/ACRE, D*LOGS/ACRE

Variable	Coefficient	Standard Error	Significance Probability > T
INTERCEPT	281.261	8.548	0.0001
SIDE SLOPE	- 1.128	0.203	0.0052
CLEARING WIDTH	- 2.001	0.127	0.0001
TREES/ACRE	0.139	0.018	0.0014
DIA*LOGS/ACRE	- 0.011	0.001	0.0001

Coefficient of Determination (R squared) = 0.995

* Definition of variables in Appendix 1

Table 5-7 GLM Regression Analysis: Balanced Use Projects

Variable entered*: SIDE SLOPE, CLEARING WIDTH, CLEARING CLASS, ADV, MONTH

Variable	Coefficient	Standard Error	Significance Probability > T
INTERCEPT	160.553	18.395	0.0001
SIDE SLOPE	- 0.793	0.333	0.0229
CLEARING WIDTH	- 0.832	0.415	0.0527
CLEARING CLASS	- 17.162	4.915	0.0013
ADV	- 0.029	0.012	0.0196
MONTH	6.694	1.770	0.0006

Coefficient of Determination (R squared) = 0.635

* Definition of variables in Appendix 1

Chapter 6. Estimating Backhoe Pioneering Production and Costs

The third major objective of the study was to estimate Backhoe pioneering and subgrading costs using production estimates obtained from the regression analysis. When total labor and machine hours can be reasonably predicted, construction cost can be estimated by applying the prevailing wage and equipment rental rates. In general, pioneering and subgrading costs take the form:

Cost = Machine hours * Machine Rent per hour
+ Labor hours * wage rate + overhead + profit

In the following analysis, machine and labor hours for the pioneering backhoe were estimated with the regressions presented in Tables 5-4 and 5-7 (shown below as equations 6-1 and 6-2). Recommended ranges for the regression variables are presented in Table 6-1 along with the mean (or mode), standard deviation, and range of the data base. The recommended ranges represent 90 percent of the likely values if the actual variable values are normally distributed and have means and standard deviations the same as the sample data (Z = 1.65):

Range = Mean (+-) 1.65 * Sdev

Machine and labor hours for other components of the construction system were estimated by tying their production to the backhoe or by applying average production rates obtained during the study. Labor and equipment rental rates were obtained from the U.S. Forest Service Region 1 Cost Guide (May 1985) and include an extra 5 percent for profit and overhead. Following the example problems is a comparison of costs estimated using the regression equations with costs calculated from the actual production rates for a specific balanced use project.

Equation 6-1:

PXRATE = 145.225 - 16.271 PXCV - 1.096 CLRWTH
-16.026 CLRCLS - 0.030 (ADVGR * ADVLG) + 6.734 MONTH

Equation 6-2:

PSRATE = 160.553 - 0.793 SLOPE - 0.832 CLRWTH
- 17.162 CLRCLS - 0.029 (ADVGR * ADVLG) + 6.694 MONTH

Table 6-1 Suggested Application Range For Eqn's 6-1 and 6-2

Variable	Mean	Standard Deviation	Data Range	Suggested Range
SSLOPE	46.44	11.87	15 - 70	27 - 66
PXCV	0.76	0.53	0.06 - 2.20	*
CLRWTH	47.51	9.90	29 - 66	31 - 64
CLRCLS	Mode = 3	0.74	1 - 5	1 - 4
ADVGR	3.97	3.34	0 - 12	0 - 9.5
MONTH	Mode = 8	1.88	2 - 12	6 - 10

* Calculate PXCV with suggested SSLOPE range

PROBLEM:

A 1.5 mile long spur road is to be constructed through medium and heavy density timber on moderate terrain. Most of the excavation is common and the site is well drained. Slash will be placed in a permanent windrow at the toe of the fill and logs will be decked in designated areas. The balanced use backhoe construction system consists of two timber fallers, a Caterpillar 235 hydraulic backhoe and operator, and a John Deere 740B grapple wheel skidder and operator. Construction will take place during July.

A survey of the right of way indicates fairly homogeneous site and road design factors on the following sections.

Estimate backhoe pioneering production and clearing and grubbing cost.

	Begin Station - End Station		
	0-23	23-56	56-79.2
Avg Side Slope %	45	36	57
Avg. Clearing Width (ft)	40	37	53
Clearing Class*	3	3	4
Avg Favorable Grade	6	5	8
Percent Length in Favorable Grade	39	15	100
Avg Adverse Grade	-2	-6	0
Percent Length in Adverse Grade	69	85	0

* 1 = X-Light , 2 = Light, 3 = Medium, 4 = Heavy, 5 = X-Heavy

SOLUTION:

1) Estimate pioneering rate using average side slope.

Equation 6-2:

$$PSRATE = 160.553 - 0.793\ SLOPE - 0.832\ CLRWTH - 17.162\ CLRCLS - 0.029\ (ADVGR * ADVLG) + 6.694\ MONTH$$

Station 0 to 23

$$PSRATE = 160.553 - 0.793\ (45) - 0.832\ (40) - 17.162\ (3) - 0.029\ (2 * 69) + 6.694\ (7)$$

$$= 83.0 \quad ft/hr$$

Station 23 to 56

PSRATE = 160.553 - 0.793 (36) - 0.832 (37) - 17.162 (3)
- 0.029 (6 * 85) + 6.694 (7)

= 81.8 ft/hr

Station 56 to 79.2

PSRATE = 160.553 - 0.793 (57) - 0.832 (53) - 17.162 (4)
- 0.029 (0) + 6.694 (7)

= 49.5 ft/hr

2) Calculate total machine and labor hours

Pioneering backhoe machine and operator hours:

PBHOURS = 2300/83.0 + (5600 -2300)/81.8
+ (7920 - 5600)/49.5

= 114.9 hrs

Wheel Skidder machine and operator hours :

The wheel skidder works with the backhoe, so has the same production rate.

WSHOURS = 114.9 hrs

Timber Faller hours: Assume the timber fallers have (on the average) the same production rate as the backhoe.

TFHOURS = 114.9 (2) = 229.8 hrs

3) Calculate clearing and grubbing costs

Cat 235 Rental Rate (new) = $ 108.00 / hr

Operator wage = 24.52 / hr

JD 540B Rental Rate (new) = 36.20 / hr

Operator wage = 24.00 / hr

Timber Faller = 21.91 / hr

Saw Rent = 2.50 / hr

CGCOST = 114.9 (108.00 + 24.52 + 36.20 + 24.00 + 2.50)
+ 229.8 (21.91 + 2.50)
= $ 28,040.20

CGCOST per mile = 28,040.20 / 1.5 = $ 18,693.46 / mi

PROBLEM:

Using the data from Example 6-1 estimate backhoe pioneering production and clearing and grubbing costs based on an estimate of pioneering excavation.

SOLUTION:

1) Pioneering excavation is estimated using the methods presented in Appendix 2. The result from Example A2-2, which calculates the pioneering excavation for stations 0 to 23, is presented below. Pioneering excavation for Stations 23 to 56 and 56 to 79.2 was estimated using the computer program (BAKPRO) listed in Appendix 3.

Sta 0 - 23	Pioneering excavation, PXCV	=	0.75 cu yd/ft
Sta 23 - 56	PXCV	=	0.48 cu yd/ft
Sta 56 - 79.2	PXCV	=	0.91 cu yd/ft

2) Calculate pioneering rate from Equation 6-1:

PXRATE = 145.225 - 16.271 PXCV - 1.096 CLRWTH
-16.026 CLRCLS - 0.030 (ADVGR * ADVLG)+6.734 MONTH

Station 0 to 23

PXRATE = 145.225 - 16.271 (.75) - 1.096 (40)
-16.026 (3) - 0.030 (2)(69) + 6.734 (7)
= 84.1 ft / hr

Station 23 to 56

PXRATE = 145.225 - 16.271 (.48) - 1.096 (37)
-16.026 (3) - 0.030 (6)(85) + 6.734 (7)
= 80.6 ft / hr

Station 56 to 79.2

PXRATE = 145.225 - 16.271 (.91) - 1.096 (53)
-16.026 (4) - 0.030 (0) + 6.734 (7)
= 55.4 ft / hr

2) Calculate total machine and labor hours

Pioneering backhoe machine and operator hours:

PBHOURS = 2300/84.1 + (5600 -2300)/80.6
+ (7920 -5600)/55.4
= 110.2 hrs

Wheel Skidder machine and operator hours : The wheel skidder works with the backhoe, so has the same production rate.

WSHOURS = 110.2 hrs

Timber Faller hours: Assume the timber fallers have (on the average) the same production rate as the backhoe.

TFHOURS = 110.2 (2) = 220.3 hrs

3) Calculate clearing and grubbing costs

Cat 235 Rental Rate (new)	=	$ 108.00 / hr
Operator wage	=	24.52 / hr
JD 540B Rental Rate (new)	=	36.20 / hr
Operator wage	=	24.00 / hr
Timber Faller	=	21.91 / hr
Saw Rent	=	2.50 / hr

CGCOST = 110.2 (108.00 + 24.52 + 36.20 + 24.00 + 2.50)
+ 220.3 (21.91 + 2.50)
= $ 26,890.77

CGCOST per mile = 26,890.77 / 1.5 = $ 17,927.18 / mi

Cost Comparison With Project Data

Estimated pioneering production and costs were compared with actual data from Wolf Mountain. The Wolf Mountain data contains production information on backhoe pioneering and slash disposal for three road sections of fairly homogeneous site factors. The combined length of these sections represent 15 percent of the project total. Pioneering excavation and pioneering rate were estimated for each section using the Type 2 cross section (Appendix 2) and the regression Equation 6-1. Estimated pioneering cost was determined using wage and machine rental rates obtained from the U.S. Forest Service Region 1 Cost Guide (May 1985).(5) These same rates were applied to the actual production data for comparison and may not reflect the contractors true costs. Calculations for section 55 to 99 are shown. Values for other sections are summarized in Table 6-4, 6-5, 6-6, 6-7 and 6-8 along with project averages.

Calculations Stations 55 to 99

1) Costs based on Actual Production

This was a balanced use construction system consisting of a Caterpillar 235 hydraulic backhoe (the pioneering backhoe), a Caterpillar 215 hydraulic backhoe (the slash disposal backhoe), a Caterpillar 966 wheel loader, and a Caterpillar D7 Dozer with U-blade and rippers. The crew consisted of 2

sawyers and 4 operators. The wheel loader operator limbed and bucked logs missed by the fallers. Slash disposal was pile and burn throughout. Right of way felling is assumed to progress at the same rate as the pioneering backhoe. An average slash disposal rate was determined from the Wolf Mountain project data and was used to estimate actual slash disposal costs. This value was compared to estimated slash disposal costs based on the average slash disposal rate computed from the data of several projects. There was not enough information on dozer excavation in the Wolf Mountain data to compute an average subgrade excavation rate, so the overall average from several projects was used to calculate subgrade dozer costs. The test sections forming the basis of the average slash disposal and average subgrade excavation rates are shown in Table 6-1.

Section 55 - 99 Production Data

Cat 235 pioneering time	=	64.0	hrs
Felling time in section	=	64.0	hrs
Cat 215 and Cat 966 Slash disposal time	=	49.7	hrs
D7 subgrade excavation time	=	44.0	hrs
Clearing area in section	=	4.55	ac
Design Excavation in section	=	6,600	cu yds

Labor and Rent Rates

Cat 235 rent with operator	=	$ 129.78	/ hr
Cat 215 rent with operator	=	$ 73.98	/ hr
Cat 966 rent with operator	=	$ 94.03	/ hr
Cat D7 rent with operator	=	$ 110.61	/ hr
Sawyers wage	=	$ 18.49	/ hr
Saw rent	=	$ 2.50	/ hr

1) Costs based on actual Production

Clear, grub and pioneer cost = backhoe cost + falling cost + slash disposal cost

APRO CGPCOST = 64.0 (129.78) + 64.0 (2) (18.49 + 2.50) + 49.7 (73.98 + 94.03 + 2.50)

= $ 19,466.99

APRO CGPCOST / mile = $\frac{19,467.00\ (5280)}{4400}$ = $23,360.38 / mi

Subgrading cost = CGPCOST + Dozer excavation cost

APRO SUBGCOST = 19,467.00 + 44.0 (110.61)

= $ 24,333.83

APRO SUBGCOST / mi = $\frac{24,333.83\ (5280)}{4400}$ = $ 29,200.60 /mi

2) Costs based on Production Estimate

Estimate Pioneering Rate:

(Values for equation 6-1 variables from Table 6-5)

Est pioneering excavation = 0.42 cy/ft

Clearing Width = 45 ft

Clearing Class = 3

ADVGR * ADVLG = 0

Month of construction = 6

Equation 6-1:

$$PXRATE = 145.225 - 16.271\ PXCV - 1.096\ CLRWTH - 16.026\ CLRCLS - 0.030\ (ADVGR * ADVLG) + 6.734\ MONTH$$

$$PXRATE = 145.225 - 16.271\ (.42) - 1.096\ (45) - 16.026\ (3) - 0.030\ (0) + 6.734\ (6)$$

$$= 81.2 \text{ ft/hr}$$

Total pioneering time = 4400 / 81.2 = 54.2 hrs

Timber felling time = 54.2 (2) = 108.4 hrs

Average slash disposal rate = 85 ft/hr (Table 6-3)

Slash disposal time = 4400 / 85 = 51.8 hrs

Average dozer excavation rate = 100 ft/hr (Table 6-2)

Dozer subgrade excavation time = 4400 / 100 = 44.0 hrs

$$\text{EST CGPCOST} = 54.1\ (129.78) + 108.4\ (18.49 + 2.50) + 51.8\ (73.98 + 94.03 + 2.50)$$

$$= \$\ 18{,}124.63$$

$$\text{EST CGPCOST / mile} = \frac{18{,}124.63\ (5280)}{4400} = \$\ 21{,}749.56/\text{mi}$$

$$\text{EST SUBGCOST} = 18{,}124.63 + 44.0\ (110.61)$$

$$= \$\ 22{,}991.47$$

$$\text{EST SUBGCOST / mile} = \frac{22{,}991.47\ (5280)}{1320} = \$\ 27{,}589.77\ /\text{mi}$$

3) Costs Based on Contractor Bid

Clearing and Grubbing Bid Price = $ 2,000.00 / ac

Excavation Bid Price = $ 0.75 / cu yd

Haul Bid Price = $ 0.04 / cu yd

$$\text{BID CGCOST} = 2{,}000.00\ (4.55) = \$\ 9{,}100.00$$

$$\text{BID CGCOST / mi} = \frac{9{,}100.00\ (5280)}{4400} = \$\ 10{,}920.00\ /\ \text{mi}$$

If backhoe pioneering excavation is added to the bid revenue for clearing and grubbing, an estimate of contractor revenue from clearing, grubbing, and pioneering is obtained:

BID CGPCOST = BID CGCOST + PXCV (Excavation bid price)

= 9,100.00 + .42 (4400) (0.75)

= $ 10,486.00

$$\text{BID CGPCOST / mi} = \frac{10{,}486.00\ (5280)}{4400} = \$\ 12{,}583.20\ /\text{mi}$$

Subgrading bid cost is the sum of clearing and grubbing bid cost plus the excavation bid cost (including haul).

BID EXVCOST = 6600 (0.75 + 0.04) = $ 5214.00

BID SUBGCOST = 4.55 (2,000.00) + 5,214.00 = $ 14,314.00

$$\text{BID SUBGCOST / mi} = \frac{14{,}314.00\ (5280)}{4400} = \$\ 17{,}176.80\ /\text{mi}$$

The above analysis was repeated for the other sections and average values computed. The results are presented in Tables 6-6, 6-7, and 6-8. On the average, estimated clearing, grubbing and pioneering costs were 12 percent less than the cost based on actual production. Estimated pioneering costs were greater than both the contractor's bid and average bid by 67 and 49 percent. Estimated subgrading costs were closer to the actual subgrading costs, with the estimated costs being about 9 percent less than the costs based on actual production. Estimated subgrade construction costs were also closer to the contractor's bid and the average bid. If these

trends were to continue in other analyses it would indicate that contractors tend to under bid clearing and grubbing then make up the difference in excavation.

Table 6-2 Dozer Subgrading Excavation Test Sections

Project	Forest	Rate ft/hr	length sta
Basin Porcp. 6	Kootenai	97.3	107
Basin Porcp. 7	Kootenai	104.7	159
Clear Creek 6	Nezperce	84.0	13
Clear Creek 7	Nezperce	75.3	28
Clear Creek 8	Nezperce	60.0	33
Clear Creek 9	Nezperce	74.1	14
Clear Creek 10	Nezperce	94.4	25
Umatilla	Nezperce	53.1	30
Dutch Anthony 9	St. Joe	83.3	50
Dutch Anthony 10	St. Joe	20.0	6
Stateline 1	St. Joe	128.0	152
Stateline 2	St. Joe	90.8	109
Stateline 3	St. Joe	153.0	46

Average Dozer Excavation Rate = 100 ft / hr

Table 6-3 Slash Disposal Test Sections (Pile and Burn)

Project	Forest	Rate ft/hr	length sta
Basin Porcp. 4	Kootenai	77.5	124
Basin Porcp. 5	Kootenai	118.6	7
Rice Paddy 4	Kootenai	86.4	146
Rice Paddy 5	Kootenai	94.3	53

Average Slash Disposal Rate (Pile and Burn) = 85 ft / hr

Table 6-4 Wolf Mountain Site and Road Design Parameters

Section sta	Design Excv cu yds	Clear Width ft	Clear Class	Side Slope %	Adv Grade (length %)	Timber Type
55-99	6600	59	3	35	0 (0)	WL/LP
148-170	4400	46	3	50	0 (0)	WL/LP
170-202	6400	56	4	40	0 (0)	DF/WL

Table 6-5 Wolf Mountain Estimated Pioneering Production

Section	Pion. Excv cy/ft	Clear Width ft	Clear Class	ADVGR * ADVLG	Month of Const	Pion. Rate ft/hr
55-99	0.42	45	3	0	6	81.2
148-170	0.88	45	3	0	6	73.4
170-202	0.53	45	4	0	6	63.6

Table 6-6 Wolf Mountain Production Data

Section	Actual Pion hours	Est Pion hours	Slash Disposal hours	Clearing Area acres	Dozer Excv hours
55-99	64.0	54.2	49.7	4.55	44.0
148-170	48.0	30.0	24.9	2.27	22.0
170-202	66.7	50.1	32.2	3.31	32.0

Table 6-7 Backhoe Pioneering Cost Comparison

Section	Actual Production C,G&P Cost	Estimated Production C,G&P Cost	Contr. R Bid C,G&P Cost	Average Bid C,G&P Cost
55-99	$ 19,466.99	$ 18,124.63	$ 10,486.00	$ 11,352.81
148-170	12,490.18	9,569.01	6,004.83	7,025.02
170-202	14,416.94	13,367.46	7,934.00	8,796.93
Avg Cost/Mi	$ 24,985.23	$ 22,122.72	$ 13,159.50	$ 14,641.10

Table 6-8 Subgrade Construction Cost Comparison

Section	Actual Production Subgrd Cost	Estimated Production Subgrd Cost	Contr. R Bid Subgrd Cost	Average Bid Subgrd Cost
55-99	$ 24,333.83	$ 22,991.47	$ 14,314.00	$18,153.45
148-170	14,923.60	12,002.43	8,016.00	10,606.93
170-202	17,956.46	16,906.98	19,265.40	15,444.29
Avg Cost/Mi	$ 30,825.44	$ 27,962.92	$ 18,321.60	$ 23,816.39

Chapter 7. Summary and Conclusions

Hydraulic backhoes have taken over a number of forest road building tasks that traditionally have been performed by dozers. Backhoes are versatile machines that offer advantages to both contractor and engineer, especially on road projects that require self-balanced excavation in moderate terrain through medium dense clearing.

This study examined thirty backhoe oriented road construction projects in northern Idaho and western Montana. Observation of backhoe road construction methods led to the categorization of backhoe construction systems into three functional types: Full use, balanced use and minimum use, depending on system organization and pioneering technique. This division was necessary in order to make an equitable comparison of production rates between contractors.

An analysis of production rates from projects in the balanced use category showed that production could be related by regression to clearing density, clearing width, steepness of grade, month of construction, and estimated volume of pioneering excavation. The volume of pioneering excavation is closely related to side slope and can be computed if backhoe dimensions are known and a self-balanced cross section assumed. Pioneering excavation volume was replaced by side slope in a second regression, with a corresponding reduction

in correlation, but the results may be easier to apply and should provide estimates as reliable as the original regression.

The regression equations can be used to estimate backhoe pioneering production rates for balanced use systems operating under conditions commonly encountered in the study region. The rate obtained should be interpreted as a high average rate that does not include extended downtime or construction delays, but does include daily maintenance and incidental repairs.

The original regression equation (based on pioneering excavation) was applied to site data from a road construction project in western Montana. Pioneering and subgrading costs based on machine and labor time were computed using the time estimate provided by the regression equation and standard Forest Service cost rates. Machine and labor time for other components in the construction system were determined either by relating their production to the pioneering backhoe or by applying overall production averages obtained during the study. These estimated costs were compared to those based on the contractors recorded production and bid price. In addition, the estimated costs were compared to costs computed from the average of all bids offered for the project.

The comparison showed that the estimated pioneering costs were 12 percent less than the costs based on actual production, but were 67 percent higher than the contractor's bid. Estimated pioneering costs were also 49 percent higher

than the average bid. These differences were reduced when dozer subgrade excavation was included, resulting in an estimated cost that was only 9 percent less than the costs based on actual production.

If the machine and labor hours approach to cost estimation is to be fully utilized in road cost estimation, more work is needed to determine usage and production of other equipment in the construction system. This study only provides an overall average production for dozer excavation and slash disposal. Additional work could extend the cost estimation procedure to include total road construction cost.

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Appendix 1

Definition of Site Factors, Terms and Variables

ADV Adverse Length % * Average Adverse Grade % A term in the pioneering rate equations which reflects the steepness and length of grade encountered by the pioneering backhoe.

ADVERSE LENGTH % The relative length of road in adverse grade calculated by dividing the length of road in adverse over a test section by the total section length, expressed as a percent. The length of adverse grade was obtained from road plans.

ADVGR An abbreviation for Average Adverse Grade %.

ADVLG An abbreviation for Adverse Length %.

APRO CGPCOST Clearing, grubbing, and pioneering cost based on actual contractor production.

APRO SUBGCOST Total subgrade excavation cost including clearing, grubbing, pioneering, and dozer subgrade excavation, based on actual contractor production.

AVERAGE ADVERSE GRADE % Adverse grade is a downhill slope in the direction of increased stationing and is based on final

design grade. Average adverse grade was calculated from road plans by determining the adverse grade for 100 ft lengths along a test section, then averaging all the adverse lengths for the test section.

AVERAGE DIAMETER The average diameter of trees in a test section from Forest Service right of way cruise statistics or by direct measurement of trees adjacent to the right of way. Timber size and density was measured using a 20 basal area factor (BAF) variable radius plot taken at approximately 500 foot intervals along the right of way.

AVERAGE FAVORABLE GRADE % Favorable grade is an uphill slope in the direction of increased stationing and is based on final design grade. Average favorable grade was calculated from road plans by determining the favorable grade for 100 ft lengths along a test section, then averaging all the favorable lengths for the test section.

AVERAGE HEIGHT The average height of trees in a test section from Forest Service right of way cruise statistics or by direct measurement of trees adjacent to the right of way. Timber size and density was measured using a 20 basal area factor (BAF) variable radius plot taken at approximately 500 foot intervals along the right of way.

BID CGCOST Clearing and grubbing cost based on a contractor's bid price. Obtained from Forest Service bid summaries.

BID EXVCOST Dozer subgrading excavation cost based on a contractor's bid price. Obtained from Forest Service bid summaries.

BID SUBGCOST Total subgrade excavation cost based on a contractor's bid price and includes clearing, grubbing, pioneering, and dozer subgrade excavation.

CLEARING CLASS A timber classification based on stem diameter and spacing used by the Forest Service to modify estimates clearing costs. Figure A1-1 is the chart used for determining clearing class obtained from the U. S. F. S. Region 1 Cost Guide for Engineering and Road Construction (May 1985). Clearing class was assigned a numerical value for use in the regression analysis: 1 for extra light, 2 for light, 3 for medium, 4 for heavy, and 5 for extra heavy.

CLEARING WIDTH Average right of way width (horizontal) determined from direct measurement or from road plans. If from road plans clearing width was calculated by dividing the total clearing area for a test section by the section length.

CLRCLS An abbreviation for clearing class.

CLRWTH An abbreviation for clearing width.

D * LOGS/ACRE Average diameter multiplied by the number or logs per acre on a test section. A factor entered into the regression analysis for estimating pioneering production for Contractor A.

D * TPA Average diameter multiplied by the number of trees per acre on a test section.

EST CGPCOST Clearing, grubbing and pioneering cost based on an estimate of pioneering production from the regression analysis and standard machine rental rates.

EST SUBGCOST Total subgrade excavation cost based on an estimate of pioneering production from the regression analysis and standard machine rental rates. Includes clearing, grubbing, pioneering and dozer subgrade excavation.

EXCAVATION PER LINEAR FOOT OF RIGHT OF WAY Total design subgrade excavation for a test section divided by the section length. The design excavation was obtained from road plans. Does not include culvert excavation.

EXCV An abbreviation of Excavation per Linear Foot of Right of Way.

FAVORABLE LENGTH % The relative length of road in favorable grade calculated by dividing the length of favorable grade over a test section by the total section length, expressed as a percent. The length of adverse grade was obtained from road plans.

HORSEPOWER Manufacturer's stated engine horsepower for a particular backhoe. Entered as a system factor in the regression analysis.

LOGS PER ACRE A measure of the number of logs that must be handled by the backhoe during clearing calculated by multiplying average tree height by the trees per acre and dividing by the standard log length, 33 feet.

MONTH OF CONSTRUCTION Month of the year when pioneering occurred.

PBHOURS Total hours that the hydraulic backhoe is clearing, grubbing and excavating the pioneer road.

PIONEERING MACHINE Make and model of the pioneering backhoe.

PIONEERING RATE Measured backhoe pioneering production on a test section expressed in linear feet of right of way per hour.

PIONEERING SYSTEM Classification of the pioneering and subgrading construction system based on system characteristics and operating methods. Explained in detail in Chapter 4.

PSRATE Backhoe pioneering rate estimated from the regression equation based on slope, clearing width, clearing class, adverse grade % * adverse length %, and month.

PXCV Estimated backhoe pioneering excavation based on machine dimensions, the geometrics of the road cross section and side slope. Calculated by the method presented in Appendix 2 or by the computer program BAKPRO listed in Appendix 3.

PXRATE Backhoe pioneering rate estimated from the regression equation based on calculated pioneering excavation, clearing width, clearing class, adverse grade % * adverse length %, and month.

SIDE SLOPE Average natural ground slope perpendicular to the center line of the right of way obtained from direct measurement or from Forest Service slope stake notes.

SOIL CLASS Classification of excavation type based on the length of road in ripable rock. A "common" designation means that the test section contained less than 5 percent ripable rock while "RR10" signifies a section with 10 percent ripable.

TFHOURS An estimate of the total hours required to fall timber on a section of road.

TIMBER TYPE Major tree species found in a test section. GF = grand fir, DF = Douglas fir, WRC = western red cedar, LP = lodge pole pine, ES = Engelmann spruce, SAF = subalpine fir, and WL = western larch.

TREES PER ACRE Tree density of a test section expressed on a per acre basis.

WSHOURS An estimate of total hours required for a wheel skidder to transport and deck logs on a section of road.

YEAR OF CONSTRUCTION Year when the road was constructed.

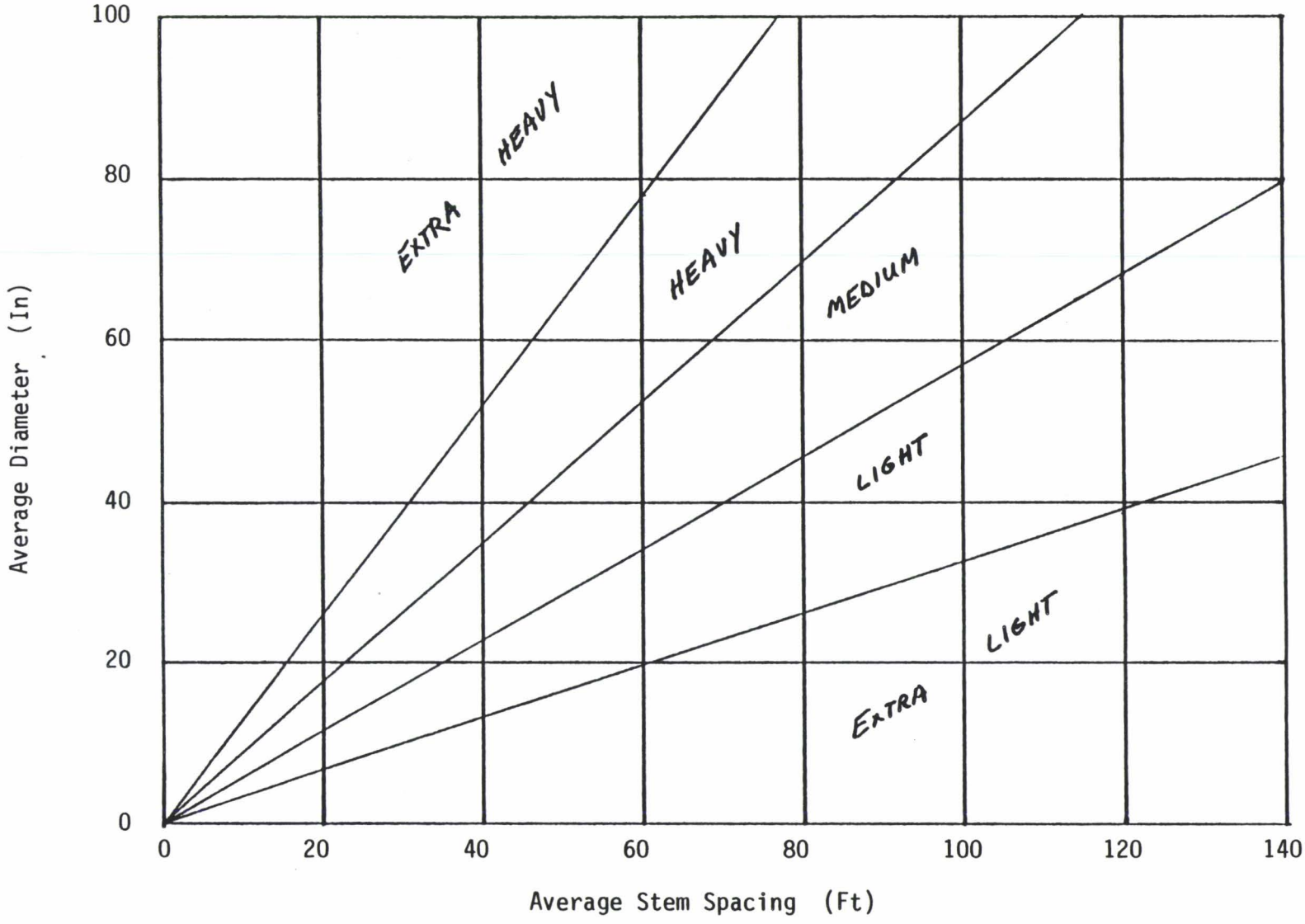

Figure A1-1. Clearing Classification, U.S. Forest Service Region One Cost Guide

Appendix 2

Estimating Backhoe Pioneering Excavation

An estimate of backhoe pioneering excavation volume, minimum clearing width, and exposed surface can be calculated from the geometry of either of the pioneering road cross sections shown in Figure 2-2 when machine dimensions, cut slope angle , fill slope angle, average side slope are known.

Type 1 Cross Section

The cross section in Figure 2-1A approximates a pioneer road cross section where the backhoe excavates a level road, the width of its tracks, and finishes the back slope. This type of road is usually found on self balanced sections on moderate side slopes. Refer to Figure 2A-1 for the definition of angles and lengths in the following equations.

$$\text{Cut area,} \quad CA = \frac{X2 \sin(A) \sin(S)}{2 \sin(A - S)} \tag{1}$$

$$\text{Let} \quad R = \frac{\sin(A) \sin(S)}{2 \sin(A - S)} \tag{2}$$

$$\text{So} \quad CA = R X^2 \tag{3}$$

$$\text{Fill area,} \quad FA = \frac{(W - X)^2 \sin(B) \sin(S)}{2 \sin(180 - B - S)} \tag{4}$$

$$\text{Let} \quad Q = \frac{\sin(B) \sin(S)}{2 \sin(180 - B - S)} \tag{5}$$

$$\text{So} \quad FA = Q (W - X)^2 \tag{6}$$

In a self balanced section the fill area is equal to the cut area multiplied by a shrinkage factor or:

$$CA = FA\ (Sf) \qquad (7)$$

Substituting (3) and (6) into (7) and expanding the polynomial gives:

$$(Q\ Sf - R)\ X^2 - (2\ W\ Q\ Sf)\ X + W^2\ Q\ Sf = 0$$

Solving the quadratic gives:

$$X = \frac{2\ W\ Q\ Sf - [(2\ W\ Q\ Sf)^2 - 4\ (Q\ Sf - R)\ (W^2\ Q\ Sf)]^{1/2}}{2\ (Q\ Sf - R)}$$

Where X is the cutbench width and the negative root of the quadratic gives the appropriate solution.

After solving for X, it can be substituted back into (3) to calculate the cut area. Then the excavation volume per linear foot of road can be calculated by:

$$PXCV = R\ X^2 / 27 \qquad (8)$$

Where X is in feet and PXCV is in cu yds per ft.

Minimum clearing width can also be calculated from the geometry if X is known. From the Law of Sines:

$$\frac{Sin(A - S)}{X} = \frac{Sin(A)}{Lc}$$

Or

$$Lc = \frac{X\ Sin(A)}{Sin(A - S)}$$

Also

$$\frac{Sin(180 - B - S)}{W - X} = \frac{Sin(B)}{Lf}$$

Or

$$Lf = \frac{(W - X)\ Sin(B)}{Sin(180 - B - S)}$$

Minimum clearing width is then calculated by:

$$Wc = Lc\ Cos(S) + Lf\ Cos(S)$$

$$= \frac{X\ Sin(A)\ Cos(S)}{Sin(A - S)} + \frac{(W - X)\ Sin(B)\ Cos(S)}{Sin(180 - B - S)}$$

Similarly, exposed road surface can be calculated where:

$$Ec = \frac{Sin(S)\ X}{Sin(A - S)} \quad \text{and} \quad Ef = \frac{(W - X)\ Sin(S)}{Sin(180 - B - S)}$$

$$So \quad Sx = W + \frac{Sin(S)\ X}{Sin(A - S)} + \frac{(W - X)\ Sin(S)}{Sin(180 - B - S)}$$

Type 2 Cross Section

The pioneer road cross section in Figure 2-1B approximates a cross section where the backhoe excavates enough for a level set with room to swing the counterweight past the cut bank. This type of pioneer road is usually found on cut and fill sections and in steeper terrain. The calculations require more machine dimensions that the first method. Figure A2-2 defines the geometry of the cross section.

Cut area is calculated by:

$$CB = Ab - Ac \qquad (9)$$

Where

$$Ab = X^2\ R,$$

R is the same as for the Type 1 cross section except the cut slope angle is dependent on machine dimensions, calculated by:

$$A = \text{Arctan (Counterweight Height/ Counterweight Overhang)}$$

$$= \text{Arctan (Ch/Co)}$$

The area of the small triangle, Ac after defining the length of one its sides, J.

$$J = \frac{X \, Sin(S)}{Sin(A - S)} - \frac{Co}{Cos(A)}$$

$$Ac = \frac{J^2 \, Sin(A - S) \, Sin(90 - A)}{2 \, Sin(90 + S)}$$

Expanding J^2 gives:

$$Ac = (N X^2 - P X + M) K \qquad (10)$$

Where

$$N = Sin^2 (S) / Sin^2 (A - S)$$

$$P = 2 \, Co \, Sin(S) / Cos(A) \, Sin(A - S)$$

$$M = Co^2 / Cos^2 (A)$$

$$K = Sin(A - S) \, Sin(90 - A) / 2 \, Sin(90 + S)$$

Substituting (10) into (9) gives:

$$CB = (R - N K) X^2 + P K X - MK \qquad (11)$$

Fill Area is calculated the same as for the Type 1 cross section:

$$FA = Q (W - X)^2 \qquad (12)$$

For a balanced section cut area equals the fill area multiplied by a shrink factor.

$$FA \, Sf = CB \qquad (13)$$

Substituting (11) and (12) into (13) and collecting like terms gives:

$$(Q\ Sf - R + N\ K)\ X^2 - (2\ W\ Q\ Sf + P\ K\ )\ X + W^2\ Q\ Sf + M\ K\ = 0$$

Solving the quadratic for X gives:

$$X = \frac{(2WQSf+PK) - [(2WQSf+PK)^2 - 4(QSf - R + NK)(W^2\ QSf + MK)]^{1/2}}{2\ (Q\ Sf - R + N\ K)}$$

Where X is the cutbench width and the negative root of the quadratic gives the appropriate solution.

After solving for X, it can be substituted back into (13) to calculate the cut area. Then the excavation volume per linear foot of road can be calculated by:

$$PXCV = Q\ Sf\ (W - X)^2\ /\ 27 \qquad (14)$$

Where X is in feet and PXCV is in cu yds per foot.

Minimum clearing width can be calculated with Lf the same as for the Type 1 cross section:

$$Wc = Lf\ Cos(S) + X + Co$$

$$= \frac{(W - X)\ Sin(B)\ Cos(S)}{Sin(180 - B - S)} + X + Co$$

Exposed surface can be calculated with Ef the same as in the Type 1 cross section:

$$Es = \frac{(W - X)\ Sin(S)}{Sin(180 - B - S)} + W + (X + Co)\ Tan(S) - Co\ Tan(A) + Co\ /\ Cos(A)$$

Example Calculation For Type 1 Cross Section

PROBLEM:

The data from Example 6-1 is repeated here along with additional road specifications. Estimate pioneering excavation based on a Type 1 cross section.

	Begin Station - End Station		
	0-23	23-56	56-79.2
Avg Side Slope %	45	36	57
Avg Clearing Width (ft)	40	37	53
Clearing Class*	3	3	4
Avg Favorable Grade	6	5	8
Percent Length in Favorable Grade	39	15	100
Avg Adverse Grade	-2	-6	0
Percent Length in Adverse Grade	69	85	0

*1 = X-Light , 2 = Light, 3 = Medium, 4 = Heavy, 5 = X-Heavy

Road width = 14 ft

Cut Slope is 1:1 (A = 45 degrees)

Fill Slope is 1.5 : 1 (B = 146 degrees)

Shrink Factor, Sf = 1.2 (Cut Area / Fill Area = 1.2)

SOLUTION:

Sta 0 - 23

S = Arctan(45/100) = 24.2 degrees

R = Sin(45) Sin(24.2) / 2 Sin(45 - 24.2)

= 0.4081

Q = Sin(146) Sin(24.2) / 2 Sin(180 - 146 - 24.2)

= 0.6734

Q Sf - R = .6734 (1.2) - .4081 = .3999

2 W Q Sf = 2(14)(.6734)(1.2) = 22.6262

$$X = \frac{22.6262 - [22.6262^2 - 4\ (.3999)(14^2(.6734)(1.2)]^{.5}}{2\ (.3999)}$$

= 8.18 ft

PXCV = $0.4081\ (8.18)S^2\ /\ 27$ = 1.01 cu yd / ft

****

To Calculate minimum clearing width (horizontal distance from cut stake to fill stake):

$$Wc = \frac{8.18\ \mathrm{Sin}(45)\mathrm{Cos}(24.2)}{\mathrm{Sin}(45 - 24.2)} + \frac{(14 - 8.18)\mathrm{Sin}(146)\mathrm{Cos}(24.2)}{\mathrm{Sin}(180 - 146 - 24.2)}$$

$$= 32.3 \text{ ft}$$

To calculate exposed surface in the cross section:

$$Sx = 14 + \frac{\mathrm{Sin}(24.2)(8.18)}{\mathrm{Sin}(45 - 24.2)} + \frac{(14 - 8.18)\ \mathrm{Sin}(24.2)}{\mathrm{Sin}(180 - 146 - 24.2)}$$

$$= 32.3 \text{ sq ft / ft}$$

Example Calculation For Type 2 Cross Section

PROBLEM:

Using the data from Problem A2.1 and the additional machine dimensions given below, calculate pioneering excavation based on a Type 2 cross section.

Track Width, W = 11.3 ft

Counterweight overhang, Co = 5.2 ft

Counterweight height, Ch = 3.8 ft

SOLUTION:

$A = \mathrm{Arctan}(Ch / Co) = \mathrm{Arctan}(3.8 / 5.2)$

$= 36.2$ degrees

$S = \mathrm{Arctan}(45/100) = 24.2$ degrees

$R = \mathrm{Sin}(36.2)\ \mathrm{Sin}(24.2) / 2\ \mathrm{Sin}(36.2 - 24.2)$

$= 0.5822$

$Q = \mathrm{Sin}(146)\ \mathrm{Sin}(24.2) / 2\ \mathrm{Sin}(180 - 146 - 24.2)$

$= 0.6734$

$N = \mathrm{Sin}^2(24.2) / \mathrm{Sin}^2(36.2 - 24.2) = 3.887$

$$P = 2\,(5.2)\,\sin(24.2) \,/\, \cos(36.2)\,\sin(36.2 - 24.2)$$

$$= 25.410$$

$$M = 5.2^2 \,/\, \cos^2(36.2) = 41.5243$$

$$K = \sin(36.2 - 24.2)\,\sin(90 - 36.2) \,/\, 2\,\sin(90 + 24.2)$$

$$= 0.0920$$

$$2\,W\,Q\,Sf + P\,K = 2\,(11.3)(.6734)(1.2) + 25.410\,(.0920)$$

$$= 20.6003$$

$$Q\,Sf - R + N\,K = .6734(1.2) - .5882 + 3.887(.0920)$$

$$= 0.5774$$

$$W\,Q\,Sf + M\,K = 11.3^2\,(.6734)(1.2) + 41.5243\,(.0920)$$

$$= 107.0040$$

$$X = \frac{20.6003 - [20.6003^2 - 4\,(.5774)(107.0040)]^{.5}}{2\,(.5774)}$$

$$= 6.31 \text{ ft}$$

$$PXCV = .6734\,(1.2)\,(11.3 - 6.31)^2 \,/\, 27$$

$$= 0.75 \text{ cu yds / ft}$$

****

To calculate minimum clearing width (width of cut fill section):

$$Ws = \frac{(11.3 - 6.31)\,\sin(146)\,\cos(24.2)}{\sin(180 - 146 - 24.2)} + 6.31 + 5.2$$

$$= 26.5 \text{ ft}$$

To calculate exposed surface:

$$Ex = (11.3 - 6.31)\,\sin(24.2) / \sin(180 - 146 - 24.2) + 11.3 +$$

$$(6.31 + 5.2)\,\tan(24.2) - 5.2\,\tan(36.2) + 5.2 \,/\, \cos(36.2)$$

$$= 31.1 \text{ sq ft / ft}$$

The above solutions should provide a reasonable first approximation of backhoe pioneering excavation in common excavation on side slopes from 10 to 60 percent. On flat ground the backhoe may excavate more than indicated by the equations due to stump excavation and stripping. Steep ground may require full bench excavation in place of the self balanced excavation assumed in the equations. In addition, some restrictions on the use of the above equations are imposed because of mathematical formulation. They are:

1. The fill slope must be steeper than the side slope, in order for the fill triangle to close, otherwise it would be impossible to calculate fill area.

2. If the cut slope angle and the fill slope angle are equal, and if the shinkage factor is 1, then the quadratic solution simplifies to a direct solution of X, and X will be equal to one half the road width (track width).

3. In the equations for the Type 2 cross section the side slope must be steeper than the angle A calculated from machine dimensions. For a Caterpillar 235 the minimum side slope is:

$$\text{Minimum Side Slope} = \frac{\text{Counterweight Height (100)}}{\text{X + Counterweight Overhang}}$$

For a Caterpillar 235 trial and error solution indicates that the minimum side slope is about 35 percent. For side slopes

less than this value, the Type 1 cross section with road width equal to track width is more appropriate.

The coding for a computer program (BAKPRO) written in BASICA (IBM Basic) is included in Appendix 3. This program calculates backhoe pioneering excavation based on the above equations. It offers a selection of either type cross section or a full bench section. It also compensates for the restrictions listed above and can estimate pioneering rate and total hours using the regression equation developed in chapter 4.

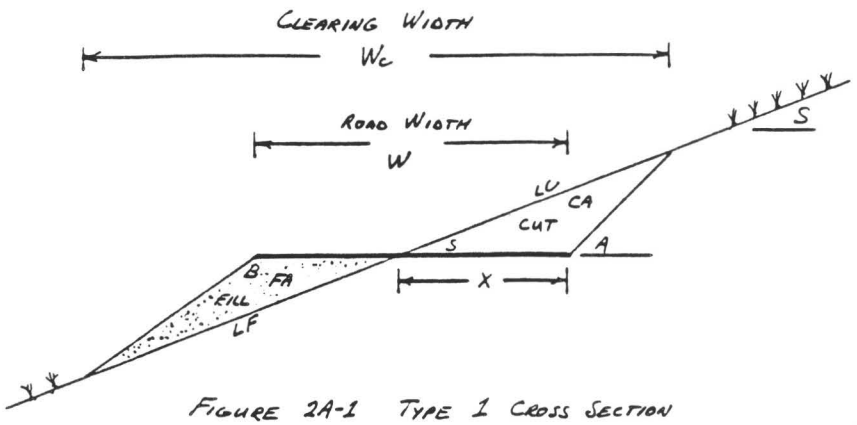

FIGURE 2A-1 TYPE 1 CROSS SECTION

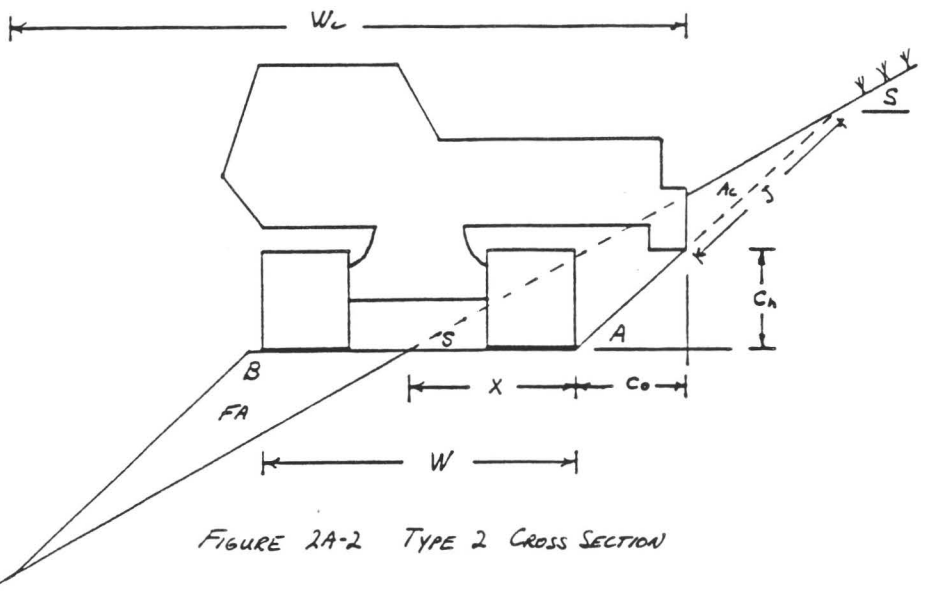

FIGURE 2A-2 TYPE 2 CROSS SECTION

Appendix 3

Hydraulic Backhoe Pioneering Production Computer Program

BAKPRO

Written in IBM BASICA

August 1985

```
1010 REM volume forest roads in northern Idaho and western Montana
1020 REM Program calculates backhoe pioneering excavation and production rates
1030 REM Gregg N. Teasdale
1040 REM Dept. of Civil Engr
1050 REM University of Idaho
1060 REM August 1985
1070 CLS: KEY OFF
1080 PRINT "**********************************************************************
1090 PRINT
1100 PRINT "            Backhoe Pioneering And Subgrading Production"
1110 PRINT
1120 PRINT "**********************************************************************
1130 PRINT
1140 PRINT "Select Pioneering Cross section"
1150 PRINT
1160 PRINT "     A:  Excavation just enough for free backhoe swing and self-bala
nced"
1170 PRINT
1180 PRINT "     B:  Excavation pulled down from cut stake and self-balanced"
1190 PRINT
1200 INPUT "     A or B  "; EX$
1210 PRINT
1220 INPUT "Do You Want Backhoe Production Calculated?  (Y or N) "; PREN$
1230 IF PREN$ = "Y" OR PREN$ = "y" THEN GOTO 1240 ELSE GOTO 1260
1240 PRINT
1250 INPUT "When Will Pioneering Occur?  ( Month, 1 - 12)"; MO
1260 PRINT
1270  STO = 0: OLDCA = 0: XTOT = 0: OLDSA = 0: SATOT = 0: PHOURTOT = 0: CLRTOT =
 0
1280 INPUT "Road Begins at Station  =  "; STO
1290 PRINT
1300 IF EX$ = "A" OR EX$ = "a" THEN CX$ = "A"
1310 IF CX$ = "A" THEN GOSUB 2040 ELSE GOSUB 3230
1320 GOSUB 1350   ' Road Total and Printing Subroutine
1330 IF CX$ = "A" THEN GOSUB 2320 ELSE GOSUB 3430  'Skips redundant imputs
1340 GOTO 1320  ' Cycles Back to Road Total and Printing Subroutine
1350 ROLENG =(STN - STO) * 100  ' Convert stations to length in feet
1360 XAV = (CAREA + OLDCA) / 2
1370 XVOL = XAV * ROLENG
1380 XTOT = XTOT + XVOL
1390 IF OLDSA = 0 THEN SAV = XSURF ELSE SAV = (XSURF + OLDSA) / 2
1400 SAREA = SAV * ROLENG
1410 SATOT = SATOT + SAREA / 43560!
1420 IF PREN$ = "Y" OR PREN$ = "y" THEN GOSUB 1760
1430 IF PREN$ = "Y" OR PREN$ = "y" THEN CLRWIH = ACLRWIH
1440 CLRAR = CLRWIH * ROLENG
1450 CLRTOT = CLRAR / 43560! + CLRTOT
1460 PRINT
1470 CUTA = CAREA * 27
1480 FMT2$ = "Cut Area At Station ###.##  =          ####.#     sq ft"
1490 PRINT USING FMT2$; STN; CUTA
1500 OLDCA = CAREA
1510 OLDSA = XSURF
1520 STO = STN
```

```
1530 PRINT
1540 FMT1$ = "Cut Volume In Section  =            #######.#     cu yd"
1550 PRINT USING FMT1$; XVOL
1560 PRINT
1570 REM "Exposed Surface  =  "; XSURF; "ft / ft"
1580 FMT3$ = "Total Cut Volume =                  #######.#     cu yd"
1590 PRINT USING FMT3$; XTOT
1600 PRINT
1610 FMT4$ = "Total Exposed Surface  =              #####.#     acres"
1620 PRINT USING FMT4$; SATOT
1630 PRINT
1640 FMT5$ = "Clearing Area In Section  =           #####.#     sq ft"
1650 PRINT USING FMT5$; CLRAR
1660 PRINT
1670 FMT6$ = "Total Clearing Area  =                #####.##    acres"
1680 PRINT USING FMT6$; CLRTOT
1690 PRINT
1700 INPUT ">>>>>>>>>  Another Section ?   (Y or N) "; ONEMORE$
1710 IF ONEMORE$ = "N" OR ONEMORE$ = "n" THEN GOTO 4250
1720 CLS
1730 PRINT "******** Enter New Section Data,  Section Begins At Station :  ";
     STO; "****"
1740 PRINT
1750 RETURN
1760 REM Backhoe Production Subroutine
1770 PRINT
1780 INPUT "Actual Clearing Width  (hit enter to use above value)"; ACLRWTH
1790 IF ACLRWTH = 0 THEN ACLRWTH = CLRWTH
1800 PRINT
1810 INPUT "Clearing Class   (1 - 5)"; CLRCLS
1820 PRINT
1830 INPUT "Road Grade, % "; GRADE
1840 PRINT
1850 IF GRADE < 0 THEN ADV = 100 * ABS(GRADE) ELSE ADV = 0
1860 PIONRATE = 145.225 - 16.721 * XAV - 1.096 * ACLRWTH - 16.026 * CLRCLS
               - .03 * ADV + 6.734 * MO
1870 CLS
1880 PRINT "***********  ROAD AND SECTION PRODUCTION SUMMARY  ****************"
1890 PRINT
1900 PRINT "                    EXCAVATION METHOD :  "; CX$
1910 PRINT
1920 PRINT "Section :"; STO; "-"; STN; "   Side Slope = "; SS; "%"; "   Grade =
"; GRADE; "%"; "   Fill Angle = "; FIX(FLANG); " Deg"
1930 PRINT
1940 PRINT "Machine :  "; MACHINE$; "   Clearing Width = "; FIX(ACLRWTH); " ft";
           "   Clearing Class = "; CLRCLS
1950 PRINT "-------------------------------------------------------------------"
1960 FMT7$ = "Backhoe Pioneering Rate  =             ####.#     ft / hr"
1970 PRINT USING FMT7$; PIONRATE
1980 PRINT
1990 PHOURS = ROLENG / PIONRATE
2000 PHOURTOT = PHOURTOT + PHOURS
2010 FMT8$ = "Total Pioneering Time  =               #####.#     hours
2020 PRINT USING FMT8$; PHOURTOT
```

```
2030 RETURN
2040 REM Begin 'A' Excavation Subroutine
2050 CLS
2060 PRINT "********************  EXCAVATION METHOD A  ************************"
2070 PRINT
2080 PRINT "Select Machine or Enter Machine Dimensions Under 'Other'"
2090 PRINT
2100 PRINT "    Cat 225    Cat 235    Hitachi UH122    Other "
2110 PRINT
2120 INPUT "     Machine =  "; MACHINE$
2130 PRINT
2140 IF MACHINE$ = "Cat 235" OR MACHINE$ = "CAT 235" OR MACHINE$ = "cat 235" OR
MACHINE$ = "CAT235" OR MACHINE$ = "cat235" OR MACHINE$ = "Cat235" OR MACHINE$ =
"Cat235" GOTO 3040
2150 IF MACHINE$ = "CAT 225" OR MACHINE$ = "Cat 225" OR MACHINE$ = "CAT225" OR M
ACHINE$ = "Cat225" OR MACHINE$ = "cat 225" OR MACHINE$ = "cat225" GOTO 3100
2160 IF MACHINE$ = "Hit uh122" OR MACHINE$ = "hit uh122" OR MACHINE$ = "Hitachi
UH122" OR MACHINE$ = "UH122" OR MACHINE$ = "HitachiUH122" OR MACHINE$ = "HITACHI
 UH122" OR MACHINE$ = "uh122" OR MACHINE$ = "hitachi uh122" GOTO 3160
2170 IF MACHINE$ = "Other" OR MACHINE$ = "other" THEN GOTO 2930 ELSE GOTO 2930
2180 REM Return here after obtaining machine dimensions
2190 PRINT "Enter Road And Soil Specifications"
2200 PRINT
2210 INPUT "     Shrink Factor "; SF
2212 SF = 1 / SF
2220 PRINT
2230 INPUT "     Fill Slope  (hoz / vert)   Hoz = "; HOZ
2240 INPUT "                                Vert = "; VERT
2250 PI = 3.141593
2260 FLANG1 = 180 - ATN(VERT / HOZ) * 180 / PI
2270 FSANG1 = FLANG1 * PI/180  'in radians
2280 PRINT
2290 REM Return here for additional sections
2300 PRINT "Enter Section Data :  Section Begins at Station :  "; STO
2310 PRINT
2320 INPUT "     Side Slope, % "; SS
2330 FLANG = FLANG1
2340 FSANG = FSANG1
2350 IF SS = 999 GOTO 4250
2360 IF SS < 60 THEN GOTO 2410
2370 PRINT
2380 INPUT "Full Bench Section  ?   (Y or N)  "; FBS$
2390 IF FBS$ = "Y" OR FBS$ = "y" THEN GOSUB 4030 ELSE GOTO 2410
2400 GOTO 2910
2410 SSR = ATN(SS/100)     'in radians
2420 IF SSR >= (PI - FSANG) THEN FSANG = PI * .75: FLANG = 135 ELSE GOTO 2430
2430 PRINT
2440 INPUT "     Station "; STN
2450 PRINT
2460 MINSS = CBHT / (.5 * TRKWTH + OVRHNG) * 100
2470 IF SS < MINSS THEN AC$ = "Y": GOTO 2480 ELSE GOTO 2510
2480 DELTR = FSANG: ALPHR = ATN(CBHT / OVRHNG)
2490 GOSUB 3600
2500 IF AC$ = "Y" THEN GOTO 2780
```

```
2510 PI = 3.141593
2520 ALPHA = ATN(CBHT / OVRHNG)    'in radians
2530 Q = SIN(SSR) * SIN(FSANG) /2 /(SIN(PI -FSANG -SSR)) * SF
2540 R = SIN(SSR) * SIN(PI - ALPHA) / 2 / SIN(ALPHA - SSR)
2550 N = SIN(SSR) ^ 2 / SIN(ALPHA - SSR) ^ 2
2560 P = OVRHNG * 2 * SIN(SSR) / COS(ALPHA) / SIN(ALPHA - SSR)
2570 M = OVRHNG ^ 2 / COS(ALPHA) ^2
2580 MM = SIN(ALPHA - SSR) * SIN(PI/2 - ALPHA) / 2 / SIN(PI/2 + SSR)
2590 A = Q - R + MM * N
2600 B = -(2 * TRKWIH * Q + MM * P)
2610 C = TRKWIH ^2 * Q + M * MM
2620 CUTWIH = (-B - SQR(B^2 - 4*A*C)) / (2*A)    ' quadratic eqn, neg root
2630 CAREA = (TRKWIH - CUTWIH) ^ 2 * Q / 27
2640 REM Calculation of Exposed Surface
2650 AS = CUTWIH * SIN(PI - ALPHA) / SIN(ALPHA - SSR)
2660 L4 = AS - (CUTWIH + OVRHNG) / COS(SSR)
2670 L5 = AS * SIN(SSR) - OVRHNG - L4 * SIN(SSR)
2680 L1 = TRKWIH
2690 L2 = OVRHNG / COS(ALPHA)
2700 L3 = (TRKWIH - CUTWIH) * SIN(SSR) / SIN(PI - SSR - ALPHA)
2710 XSURF = L1 + L2 + L3 + L4 + L5
2720 LL = (TRKWIH - CUTWIH) * COS(SSR) * SIN(FSANG) / SIN(PI - FSANG - SSR)
2730 RR = CUTWIH * SIN(PI - PI/4) * COS(SSR) / SIN(PI/4 - SSR)
2740 CLRWIH = LL + RR
2750 IF (LL - (TRKWIH - CUTWIH) > 1.5 * TRKWIH) THEN GOTO 2760 ELSE GOTO 2780
2760 FSANG = PI * .75: FLANG = 135
2770 GOTO 2510
2780 CLS
2790 PRINT "**************EXCAVATION METHOD A :  SECTION  "; STO; "-"; STN; "***
********"
2800 PRINT
2810 IF PREN$ = "Y" OR PREN$ = "y" THEN GOTO 2860
2820 PRINT "Machine =  "; MACHINE$; "     Side Slope =  "; SS; " %"; "     Fill
Angle =  "; FIX(FLANG); "  Deg"
2830 PRINT
2840 PRINT "--------------------  Road and Section Summary  ----------------"
2850 PRINT
2860 FMT9$ = "Cut Bench Width  =                        ##.#     ft"
2870 PRINT USING FMT9$; CUTWIH
2880 PRINT
2890 FMT10$ = "Minimum Clearing Width  =                ###.#     ft"
2900 PRINT USING FMT10$; CLRWIH
2910 RETURN
2920 REM End of 'A' Excavation Subroutine
2930 REM Other Machine Subroutine For Machine Dimensions
2940 PRINT "Enter Backhoe Dimensions"
2950 PRINT
2960 INPUT "     Backhoe Track Width"; TRKWIH
2970 PRINT
2980 INPUT "     Counterweight Overhang"; OVRHNG
2990 PRINT
3000 INPUT "     Counterbalance Height"; CBHT
3010 PRINT
3020 GOTO 2180
```

```
3030 REM End of 'Other Machine' Dimension Subroutine
3040 REM Cat 235 Dimension Subroutine
3050 TRKWTH = 11.33
3060 OVRHNG = 5.17
3070 CBHT = 3.75
3080 GOTO 2180
3090 REM End of Cat 235 Subroutine
3100 REM Cat 225 Dimensions Subroutine
3110 TRKWTH = 9.83
3120 OVRHNG = 4.34
3130 CBHT = 3.42
3140 GOTO 2180
3150 REM End of Cat 225 Subroutine
3160 REM Hitachi UH122 Dimension Subroutine
3170 TRKWTH = 9.83
3180 OVRHNG = 5.09
3190 CBHT = 3.75
3200 GOTO 2180
3210 REM End of Hitachi UH122 Subroutine
3220 REM End of 'A' Excavation Subroutine Including Machines
3230 REM Begin 'B' Excavation Subroutine
3240 CLS
3250 PRINT "*********************  EXCAVATION METHOD B  ************************"
3260 PRINT
3270 CX$ = "B"
3280 PRINT "Enter Road Specifications"
3290 PRINT
3300 INPUT "     Road Width (Track Width)"; TRKWTH
3310 PRINT
3320 INPUT "     Cut Slope  (Hoz / Vert)    Hoz = "; HOZC
3330 INPUT "                                Vert = "; VERTC
3340 PRINT
3350 INPUT "     Shrink Factor"; SF
3352 SF = 1 / SF
3360 PRINT
3370 INPUT "     Fill Slope  (Hoz / Vert)   Hoz = "; HOZF
3380 INPUT "                                Vert = "; VERTF
3390 PRINT
3400 REM
3410 PRINT "Enter Section Data :  Section Begins at Station :  "; STO
3420 PRINT
3430 INPUT "     Side Slope, %"; SS   'return here to skip redundant data
3440 PI = 3.141593
3450 DELTA1 = 180 - ATN(VERTF /HOZF) * 180 / PI
3460 ALPHA  = ATN(VERTC/HOZC) * 180 / PI
3470 DELTA = DELTA1
3480 IF SS = 999 GOTO 4250
3490 ALPHR = ALPHA * PI / 180
3500 IF SS < 60 THEN GOTO 3550
3510 PRINT
3520 INPUT "Full Bench Section  ?   (Y or N)  "; FBS$
3530 IF FBS$ = "Y" OR FBS$ = "y" THEN GOSUB 4030 ELSE GOTO 3550
3540 GOTO 4010
3550 DELTR = DELTA * PI / 180
```

```
3560 SSR = ATN(SS/100)
3570 IF SSR >= (PI - DELTR) THEN DELTR = PI * .75: DELTA = 135 ELSE GOTO 3580
3580 PRINT
3590 INPUT "     Station"; STN
3600 IF SS = 0 THEN GOTO 3840   'ALSO COME HERE FROM 'A' if ss < ssmin
3610 IF 180 - ALPHA = DELTA AND SF = 1! THEN GOTO 3620 ELSE GOTO 3650
3620 CAREA = (TRKWTH/2) ^ 2 * SIN(PI - ALPHR) * SIN(SSR) / 2 / SIN(ALPHR - SSR)/
27
3630 CUTWTH = TRKWTH / 2
3640 GOTO 3720
3650 QFS = SIN(DELTR) * SIN(SSR) / 2 / SIN(PI - DELTR - SSR) * SF
3660 R = SIN(PI - ALPHR) * SIN(SSR) / 2 / SIN(ALPHR - SSR)
3670 A = QFS - R
3680 B = -(2 * TRKWTH * QFS)
3690 C = TRKWTH ^ 2 * QFS
3700 CUTWTH = (-B - SQR(B ^2 - 4 * A * C)) / (2 * A)
3710 CAREA = CUTWTH ^ 2 * R / 27
3720 REM Calculation of exposed surface
3730 L1 = TRKWTH
3740 L2 = SIN(SSR) * CUTWTH / SIN(ALPHR - SSR)
3750 L3 = SIN(SSR) * (TRKWTH - CUTWTH) / SIN(PI - DELTR - SSR)
3760 XSURF = L1 + L2 + L3
3770 REM Calculation of Clearing Width
3780 LL = (TRKWTH - CUTWTH) * COS(SSR) * SIN(DELTR) / SIN(PI - DELTR - SSR)
3790 RR = CUTWTH * SIN(PI - ALPHR) * COS(SSR) / SIN(ALPHR - SSR)
3800 CLRWTH = LL + RR
3810 IF (LL - (TRKWTH - CUTWTH) > 1.5 * TRKWTH) THEN GOTO 3820 ELSE GOTO 3860
3820 DELTR = PI * .75: DELTA = 135
3830 GOTO 3610
3840 REM Come here if side slope is zero
3850 CAREA = 0: CUTWTH = 0: CLRWTH = TRKWTH: XSURF = TRKWTH
3860 IF AC$ = "Y" THEN RETURN
3870 CLS
3880 PRINT "**************EXCAVATION METHOD B :  SECTION  "; STO; "-"; STN; "***
********"
3890 PRINT
3900 IF PREN$ = "Y" OR PREN$ = "y" THEN GOTO 3950
3910 PRINT "Road Width = "; TRKWTH; " ft"; "     Side Slope = "; SS; " %"; "
Fill Angle = "; FIX(DELTA); "Deg"
3920 PRINT
3930 PRINT "------------------  Road and Section Summary  ------------------"
3940 PRINT
3950 FMT11$ = "Cut Bench Width  =                    ##.#     ft"
3960 PRINT USING FMT11$; CUTWTH
3970 PRINT
3980 FMT12$ = "Minimum Clearing Width  =             ###.#    ft"
3990 PRINT USING FMT12$; CLRWTH
4000 FLANG = DELTA
4010 RETURN
4020 REM End of 'B' Excavation Subroutine
4030 REM Begin full bench subroutine
4040 PI = 3.141593
4050 IF CX$ = "A" THEN ALPH = PI/4 ELSE ALPH = ALPHR
```

```
4060 SSR = ATN(SS/100)
4070 PRINT
4080 INPUT "Station "; STN
4090 PRINT
4100 CAREA = TRKWTH ^2 * SIN(PI - ALPH) * SIN(SSR) / 2 / SIN(ALPH - SSR) /27
4110 CUTWTH = TRKWTH
4120 CLRWTH = TRKWTH * SIN(PI - ALPH) * COS(SSR) / SIN(ALPH - SSR)
4130 XSURF = TRKWTH + TRKWTH * SIN(SSR) / SIN(ALPH - SSR)
4140 CLS
4150 PRINT "**********  Full Bench Excavation :  Station  "; STO; "-"; STN; "***
****"
4160 PRINT
4170 PRINT
4180 PRINT "--------------------  Road and Section Summary  ----------------"
4190 PRINT
4200 PRINT
4210 FMT13$ = "Minimum Clearing Width  =              ###.#     ft"
4220 PRINT USING FMT13$; CLRWTH
4230 RETURN
4240 REM End of full bench subroutine
4250 PRINT "STOP"
4260 END
```